

This is not the big bang!



Models Lecture 8

We are not the center of the expansion of the universe

Every galaxy sees the expansion

Cosmological Principle

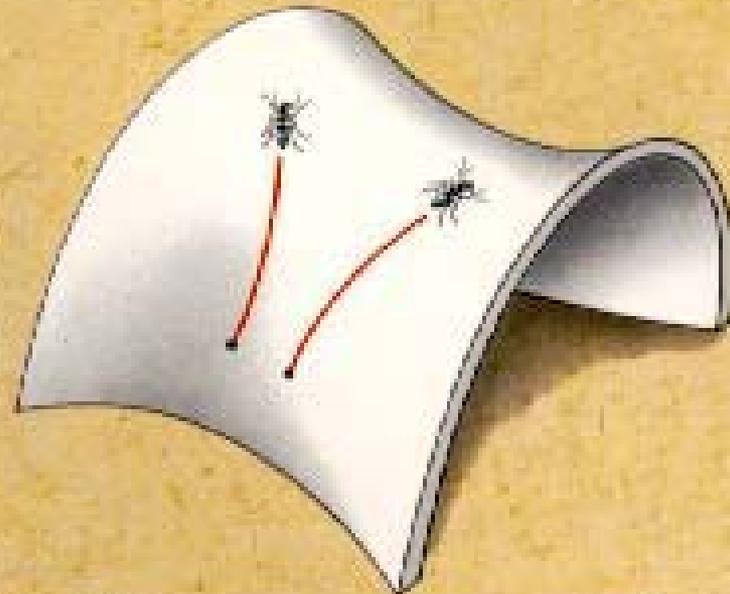
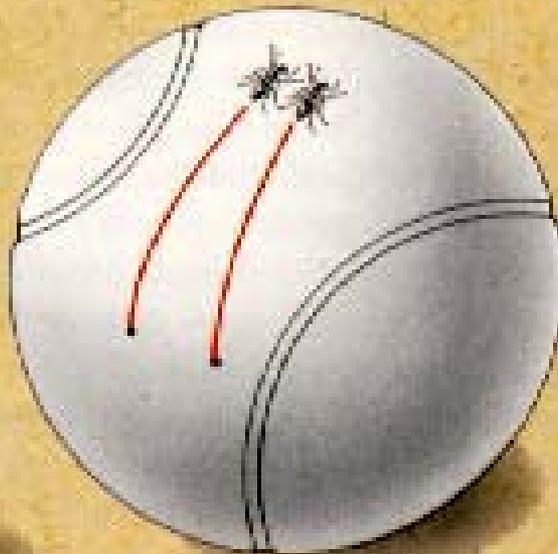
The universe is the same everywhere

- no special point in the universe
(no center)**
- no special set of points
(no edge)**

3R

3S

3H



ZERO CURVATURE

POSITIVE CURVATURE

NEGATIVE CURVATURE

FLAT

SPHERICAL

HYPERBOLIC

The expansion of the universe is

an explosion of space

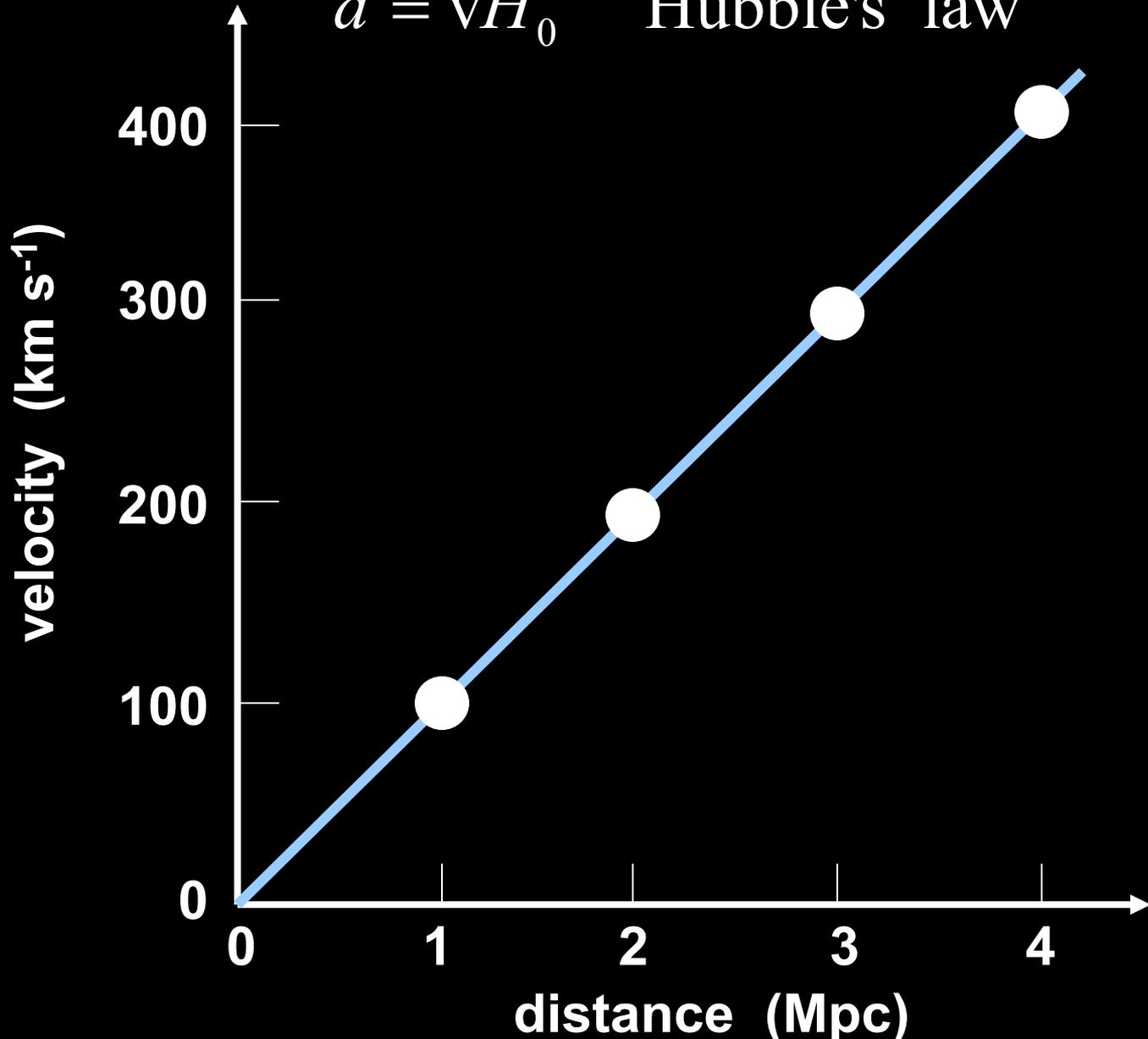
not

an explosion into space

**The universe does not expand
into anything!**

$$v = H_0 d$$

$$d = v H_0^{-1} \quad \text{Hubble's law}$$



The Hubble age of the universe

$d = vt$ distance = velocity \times time

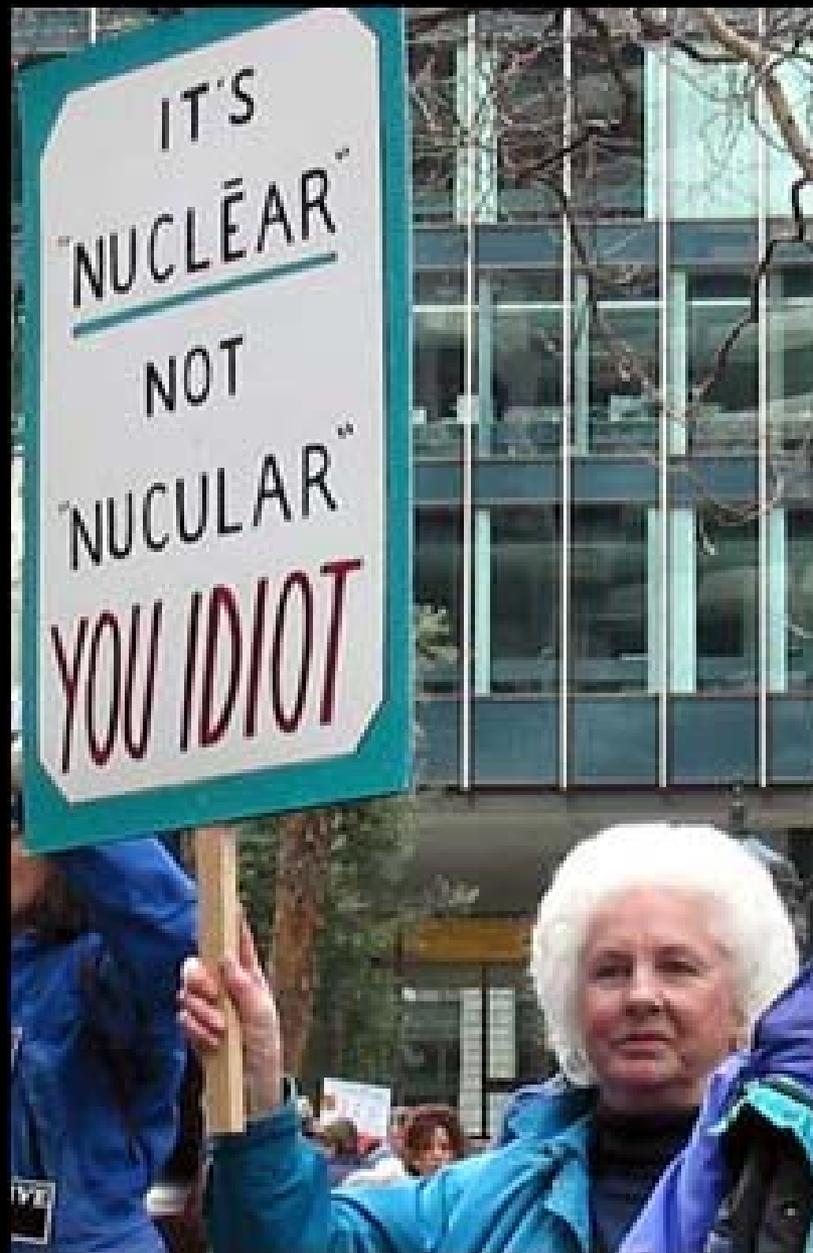
$d = vH_0^{-1}$ Hubble's law

$$t = 10^{10} h^{-1} \text{ years}$$

$$12.5 \leq t \leq 17 \text{ Gyr}$$

$$1 \text{ Gyr} = 10^9 \text{ years}$$

Nuclear Physics



Nucleus made of

● protons – charge = +1

● neutrons – charge = 0

Hydrogen
1 proton



${}^1\text{H}$



${}^2\text{H}$

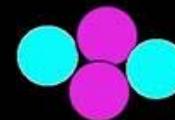


${}^3\text{H}$

Helium
2 protons



${}^3\text{He}$

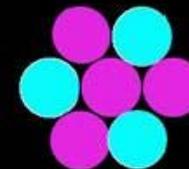


${}^4\text{He}$

Lithium
3 protons



${}^6\text{Li}$



${}^7\text{Li}$

$$\tau_{1/2}({}^{238}\text{U}) = 4.5 \text{ Gyr}$$

$$\tau_{1/2}({}^{187}\text{Re}) = 40 \text{ Gyr}$$

$$\tau_{1/2}({}^{232}\text{Th}) = 14 \text{ Gyr}$$

Age of the elements 10 – 18 Gyr

$$t = 10^{10} h^{-1} \text{ years}$$

$$12.5 \leq t \leq 17 \text{ Gyr}$$

$$1 \text{ Gyr} = 10^9 \text{ years}$$

Hubble's original value:

$$H_0 = 500 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

$$h = 5$$

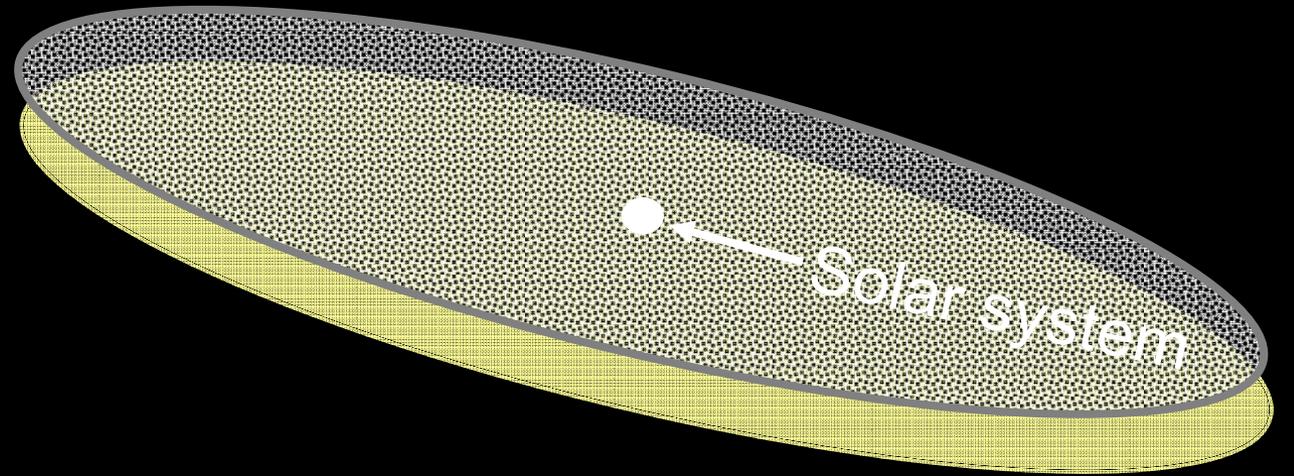
$$t = 10^{10} h^{-1} \text{ years}$$

$$t = 2 \text{ Gyr}$$

Cosmology 100 Years Ago

- 1) Nature of space and time: absolute
- 2) Origin of the Universe: not an astronomy issue
- 3) Evolution of the Universe: stationary
- 4) Arrangement of the Universe:

6,500
light years



30,000 light years

- 5) Composition of the Universe: starz' in the hood

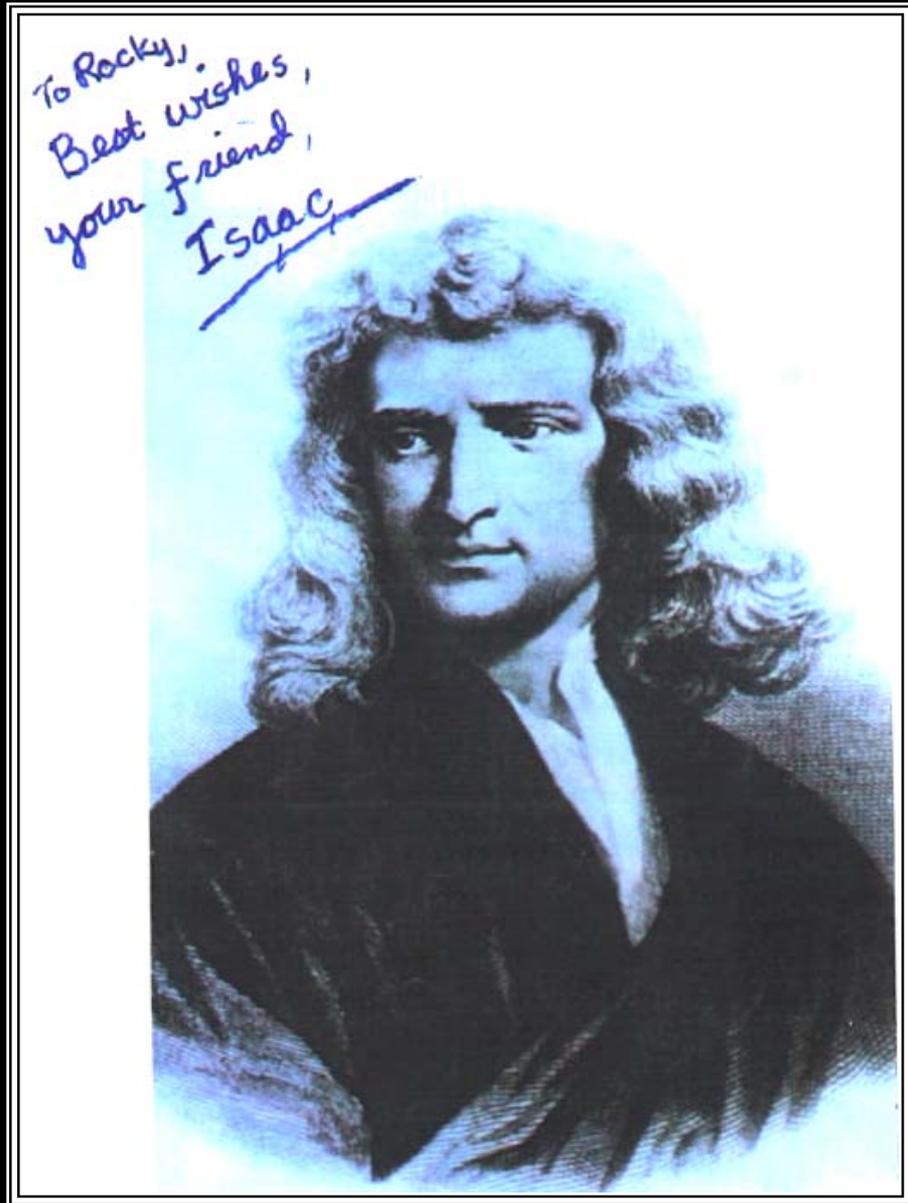
Space and Time Before Einstein

**Absolute space,
in its own nature,
without relation
to anything external,
remains always similar
and immovable.**

ISAAC NEWTON

1687

*Philosophiæ Naturalis
Principia Mathematica*



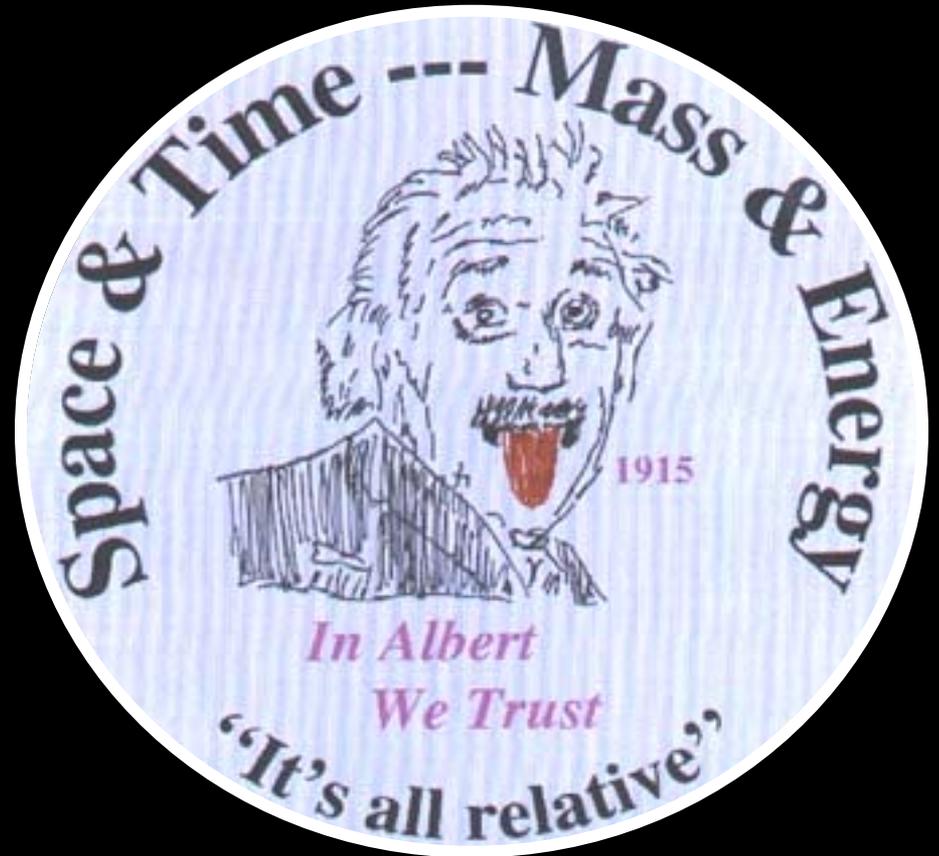
Space and Time After Einstein

**SPACE AND TIME
ARE RELATED.**

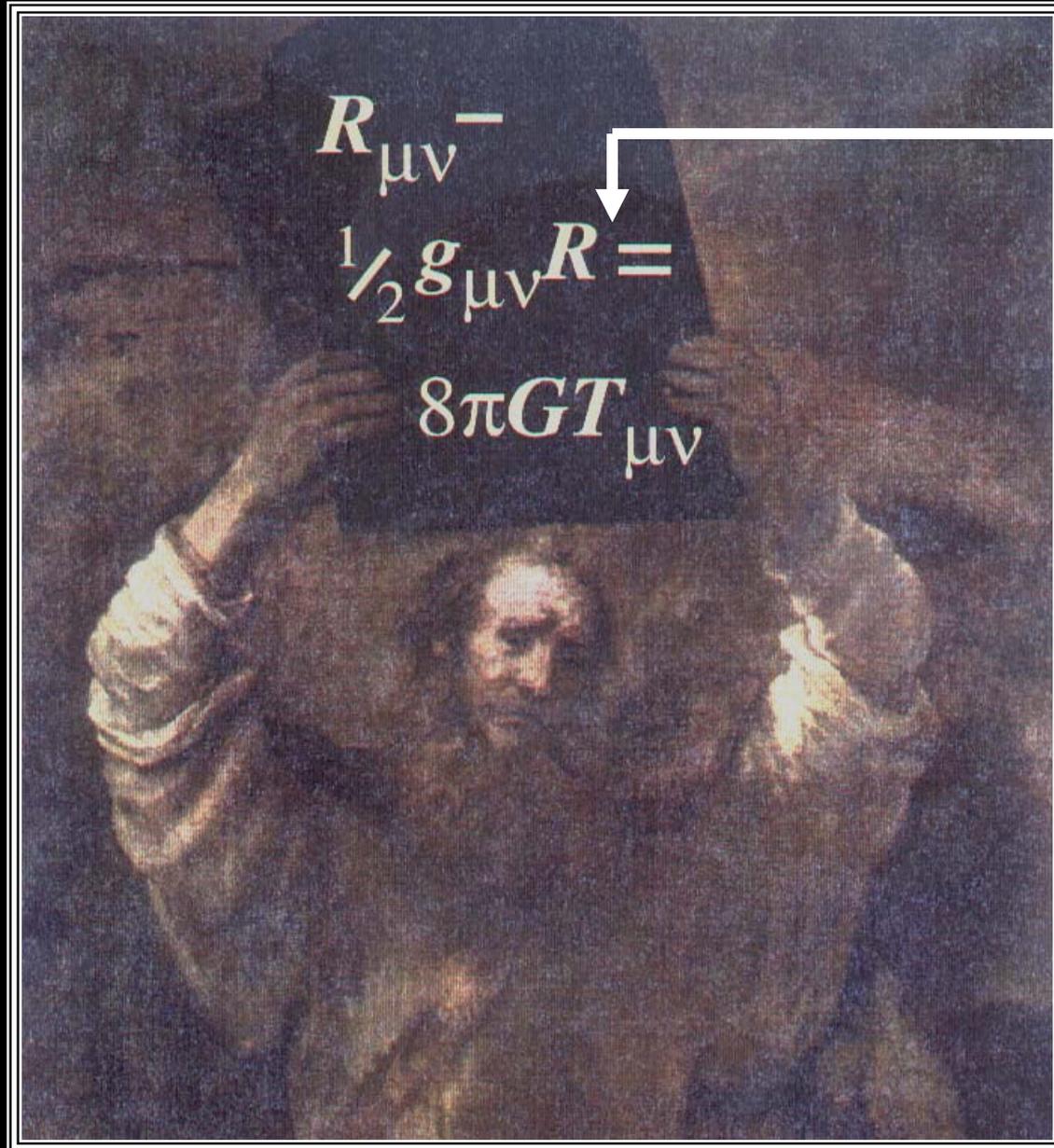
**ALBERT EINSTEIN
1905**

**SPACE IS DYNAMIC
(CURVED, WARPED,
BENT).**

**ALBERT EINSTEIN
1915**



Modern Laws of Genesis



$$+\Lambda g_{\mu\nu}$$

Einstein's Cosmic Legacy

The origin & destiny
of the universe are
amenable to human
inquiry!

Cosmology is a science!



<http://space.about.com/cs/astronomerbios/a/lemaitrebio.htm>

<http://www-groups.dcs.st-and.ac.uk/~history/Mathematicians/Friedmann.html>



**Aleksandr Aleksandrovich Friedmann
(1888-1925)**

**Georges-Henri Lemaître
(1894-1966)**

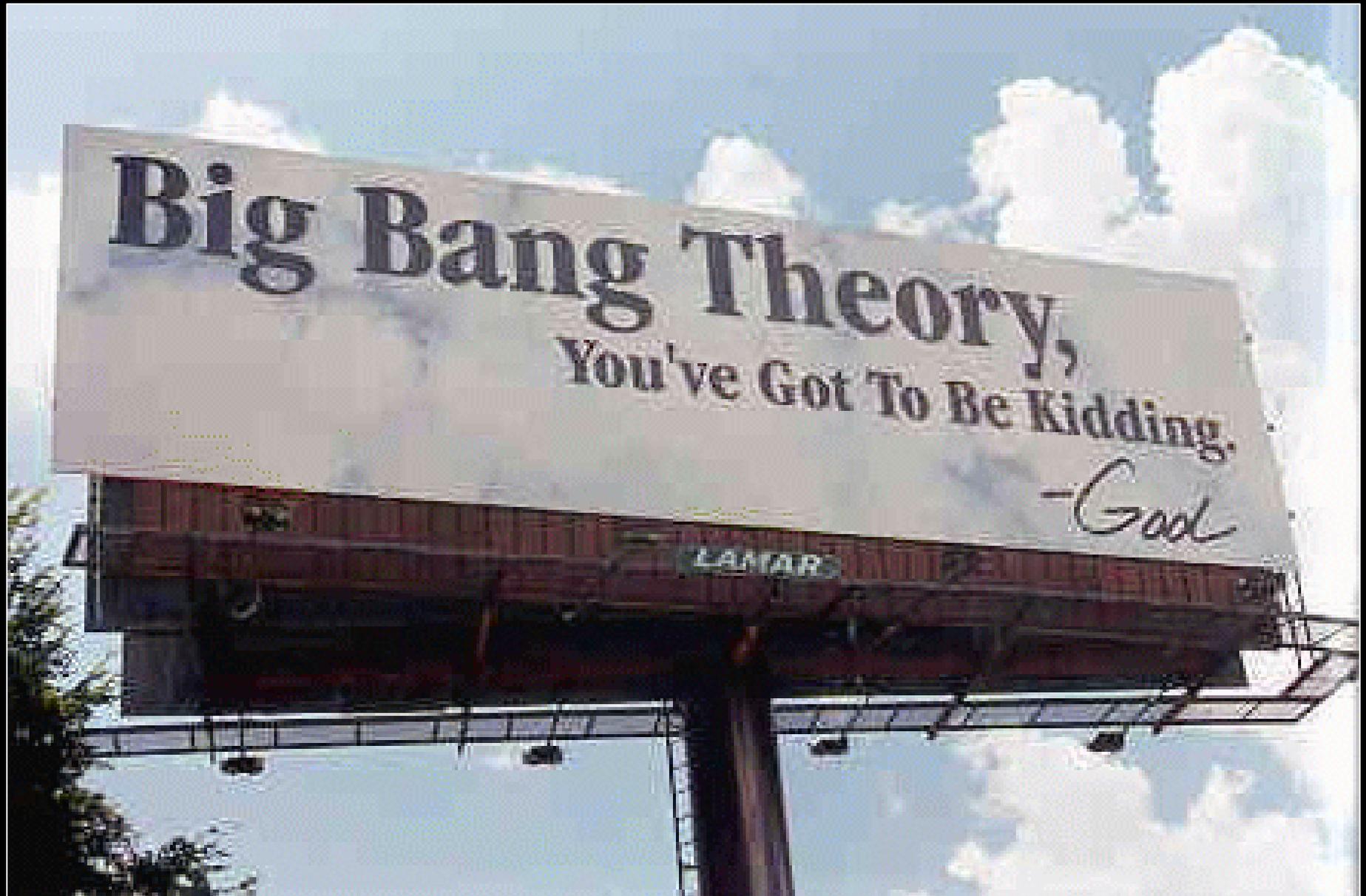


SPACE EXPANDS.

EDWIN HUBBLE
1929



The Big Bang



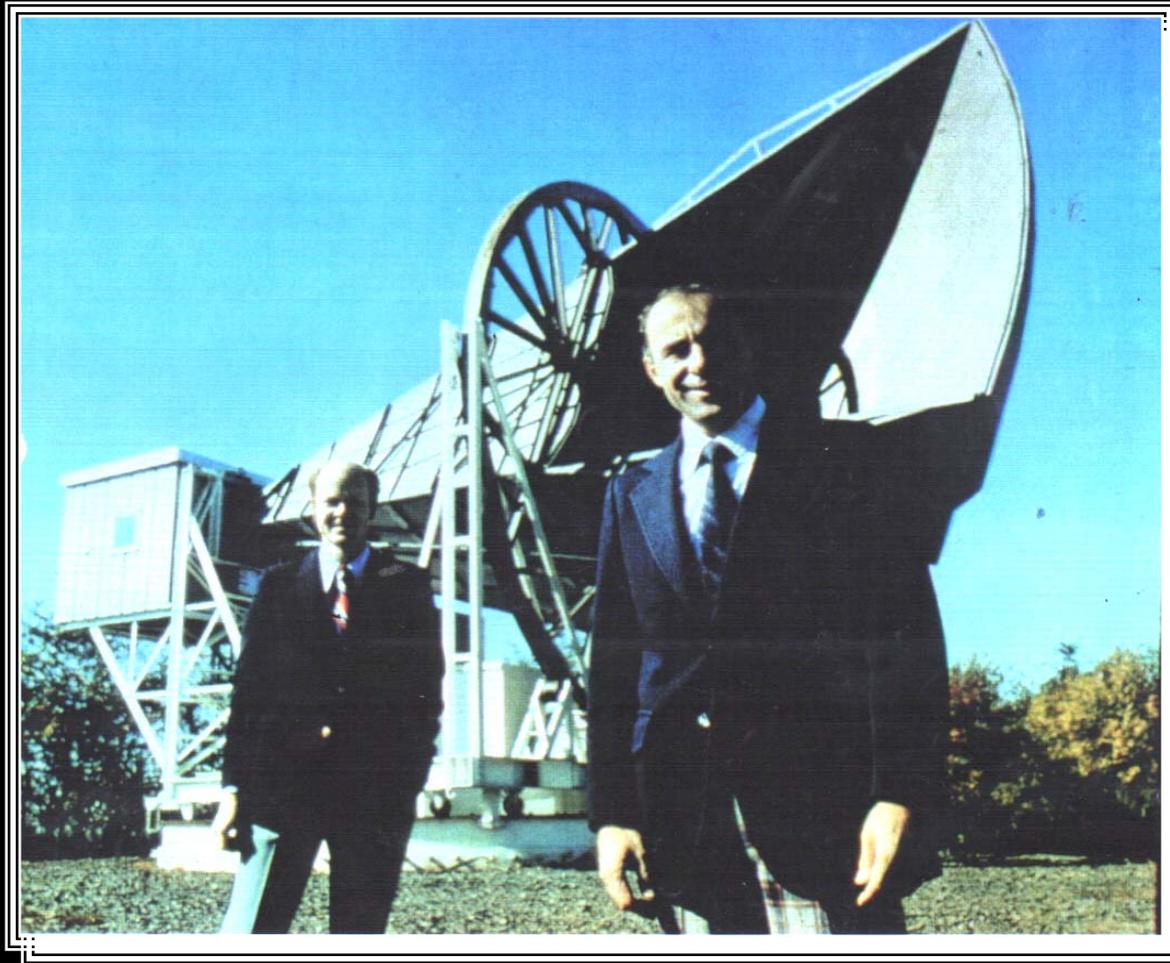


YLEM

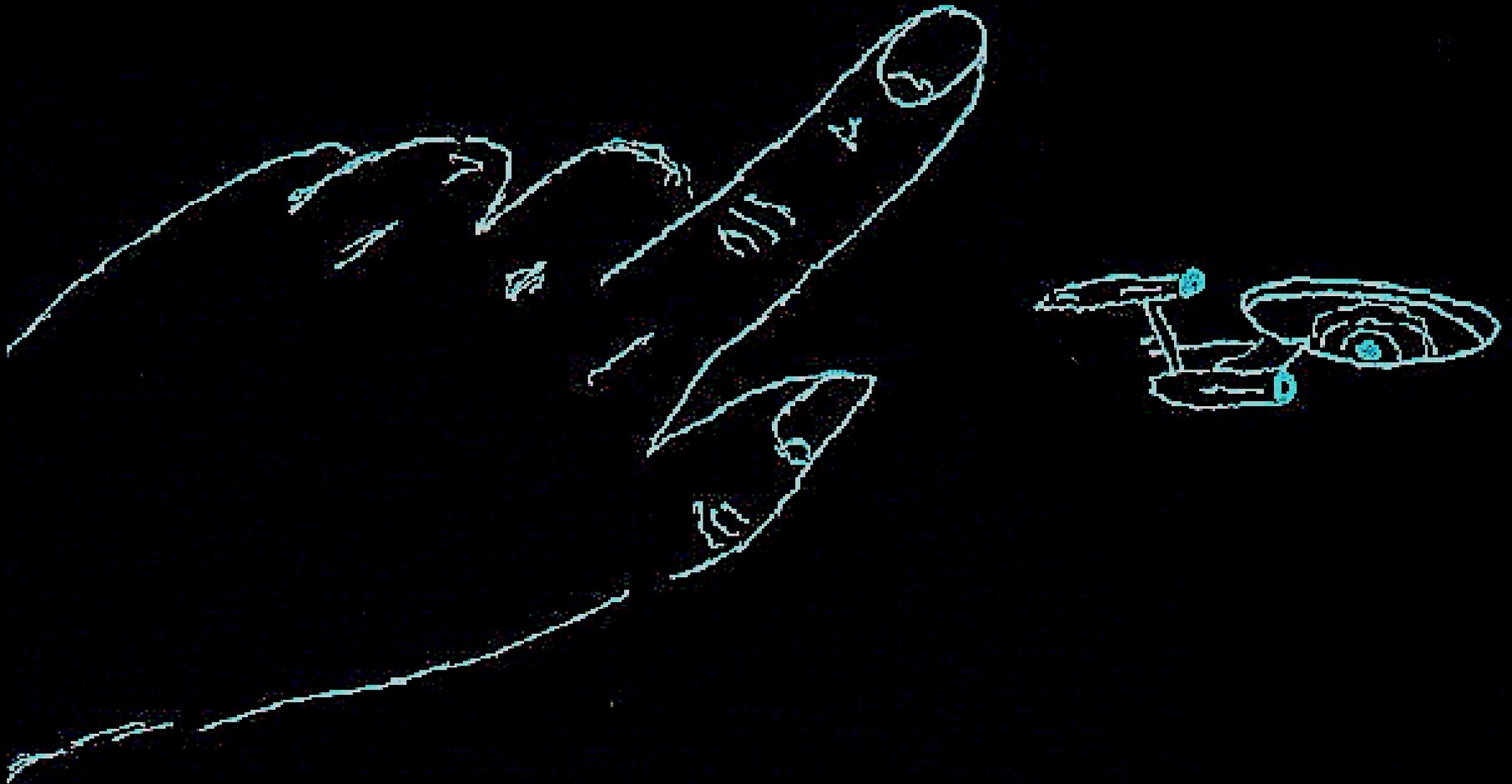
**LIQUEUR
COGNAC**

**THE UNIVERSE
IS RADIANT.**

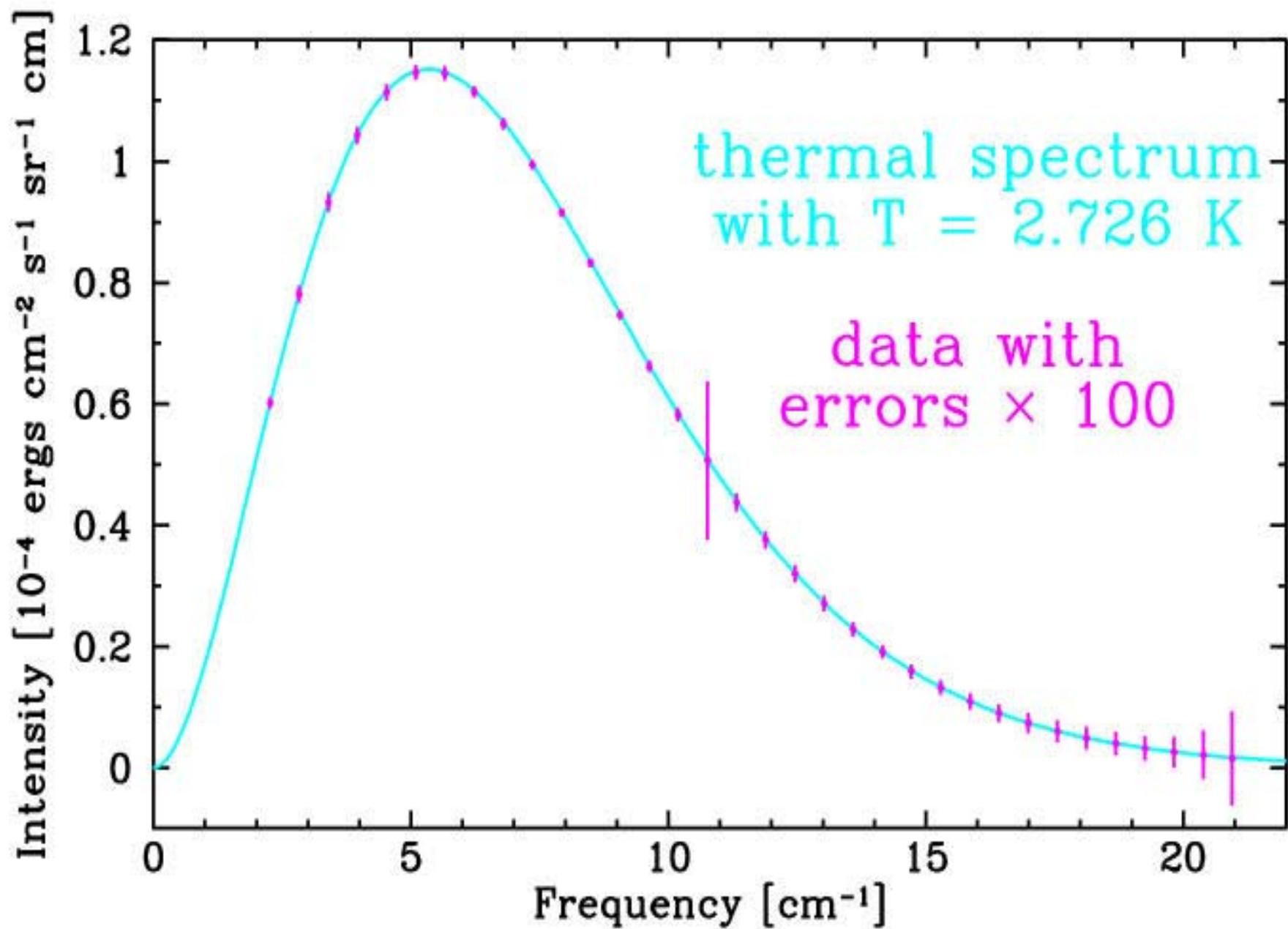
**ARNO PENZIAS
ROBERT WILSON
1965**



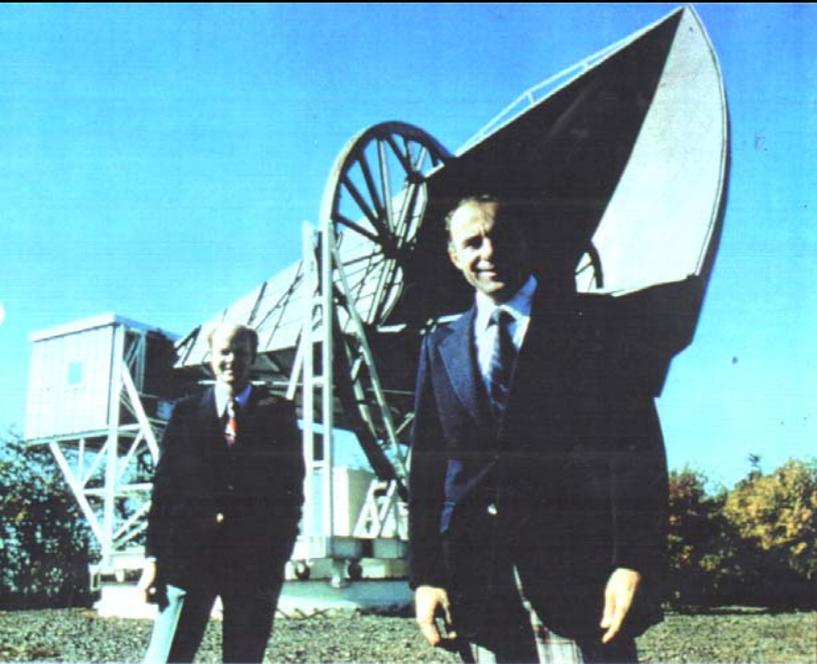
Cosmic background radiation



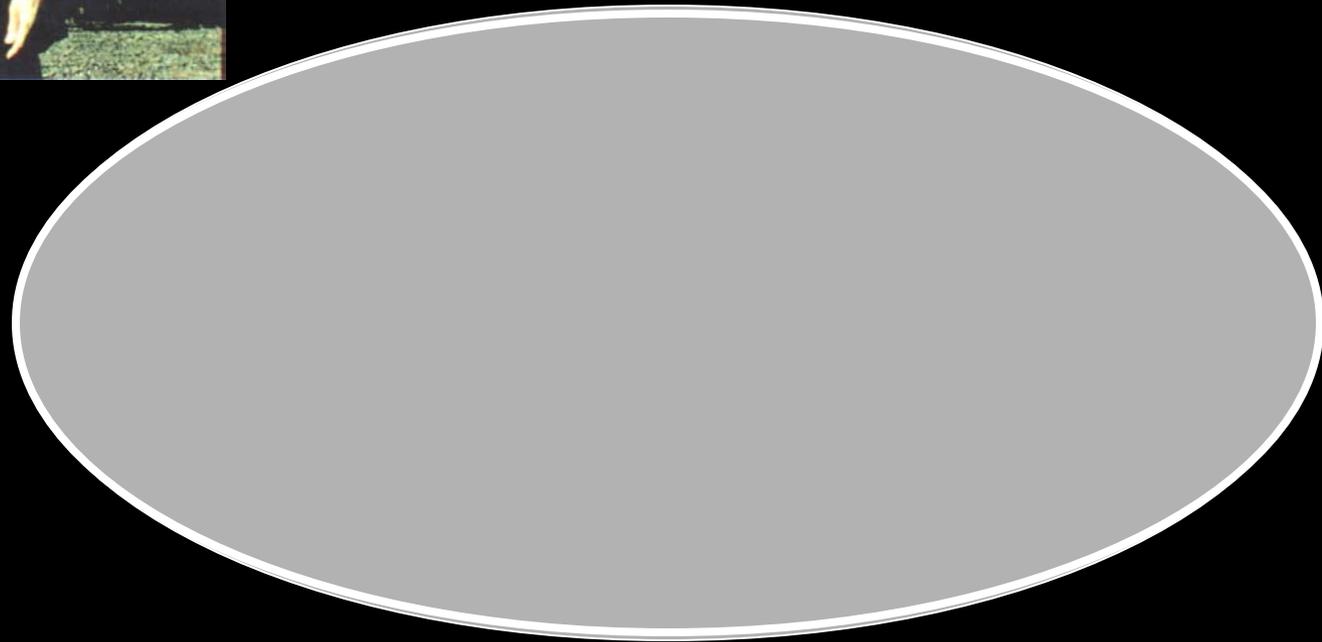
$$T = 3K = -454^{\circ} F$$



Cosmic Radiation ca. 1960s



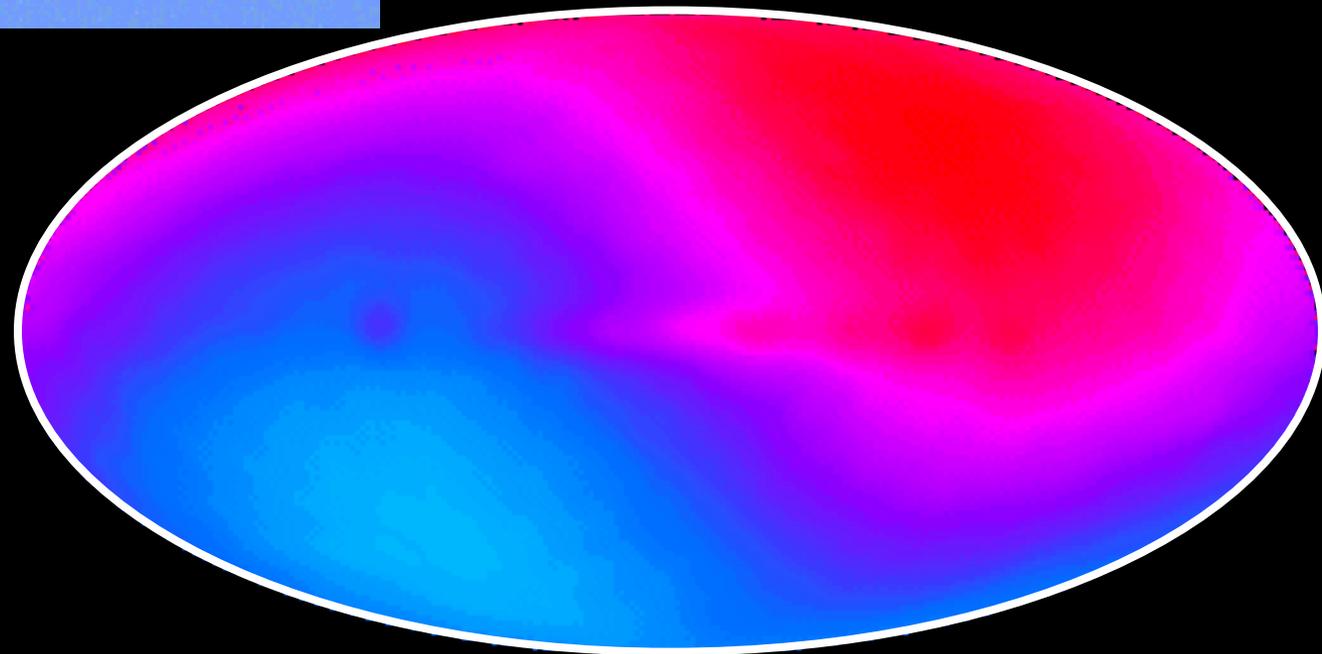
2° 3° 4°



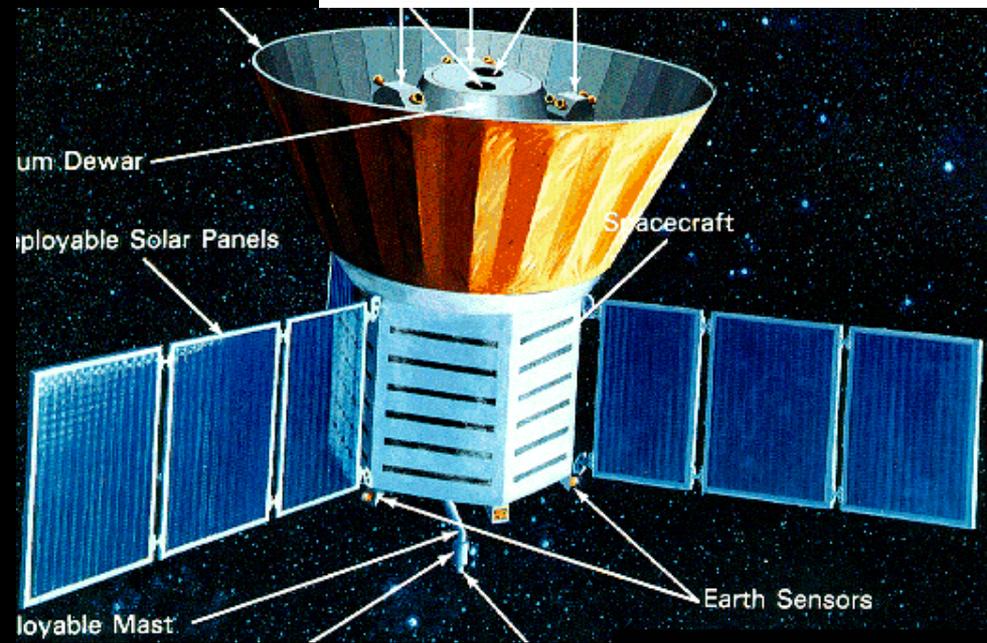
Cosmic Radiation ca. 1975



2.997° 3° 3.003°



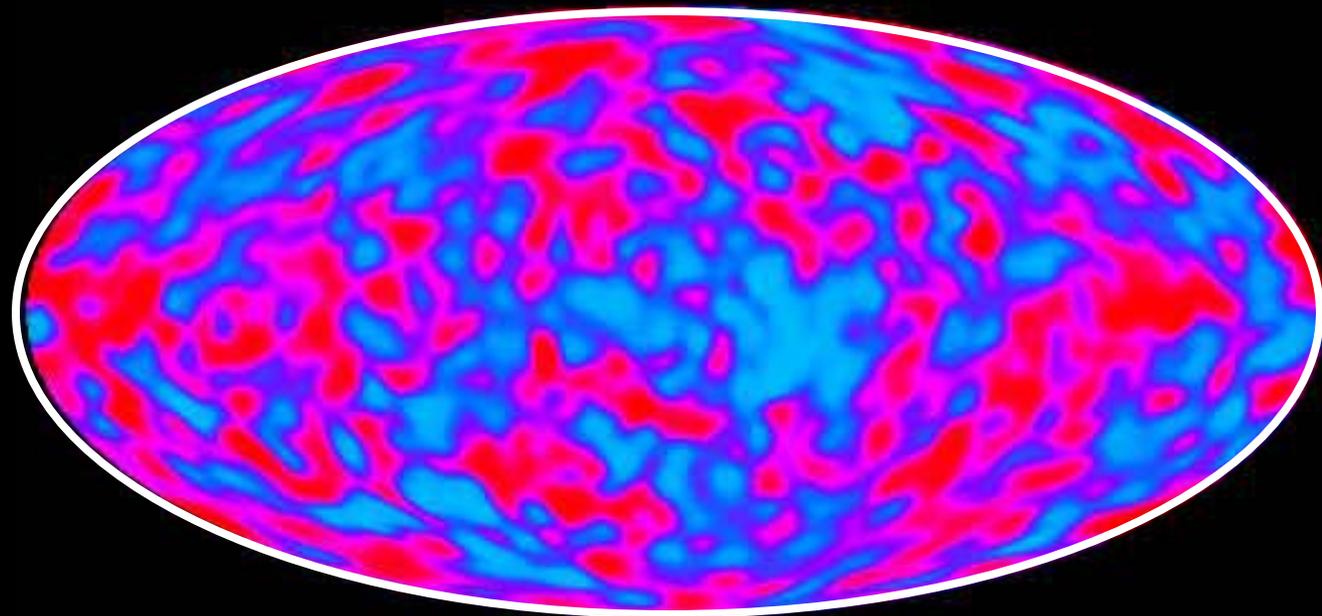
Cosmic Radiation 1992

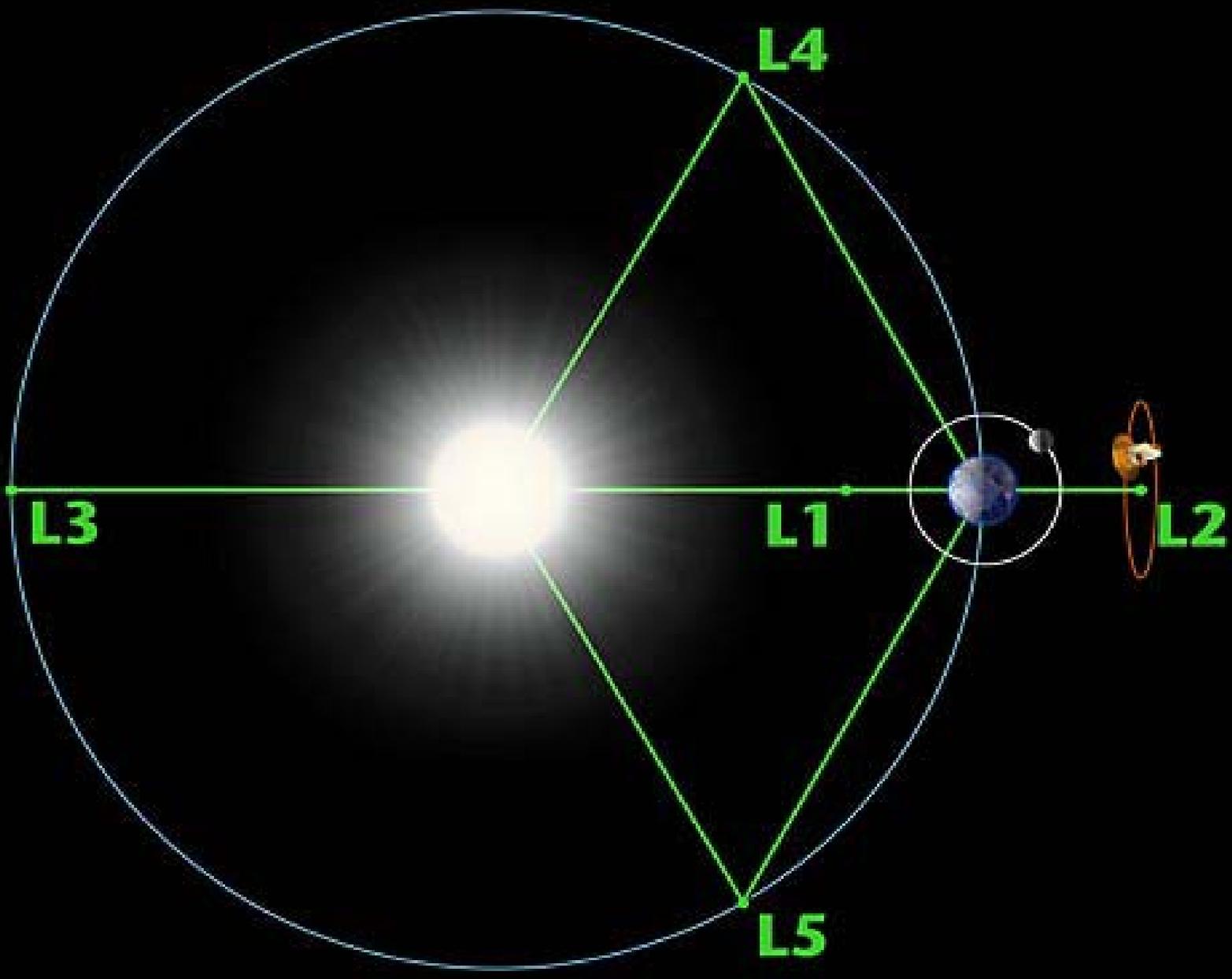


2.99997° 3° 3.00003°

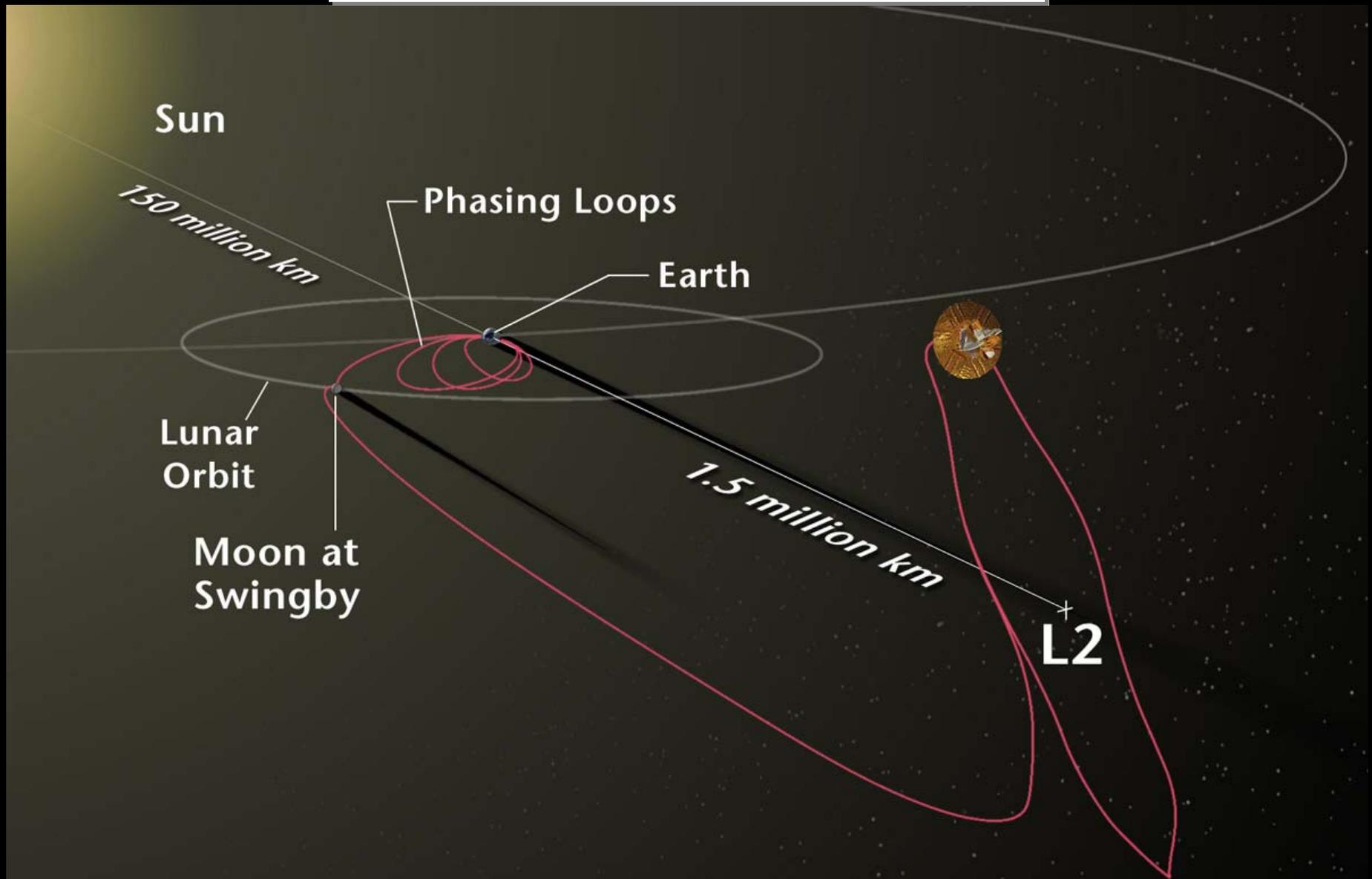


COBE





The voyage to L2



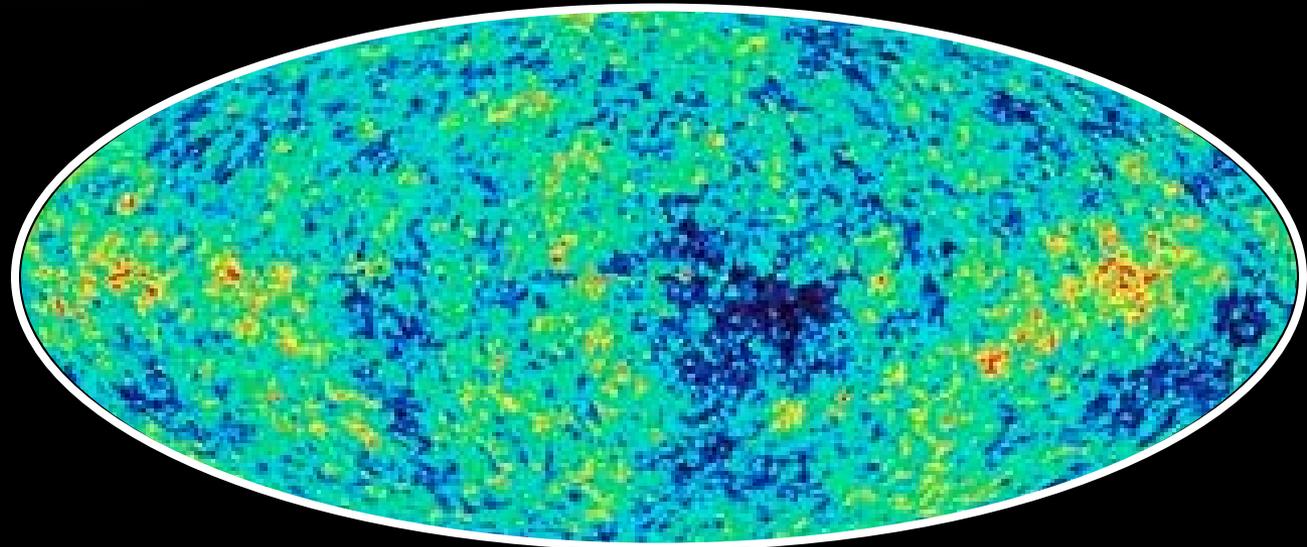
Cosmic Radiation 2005



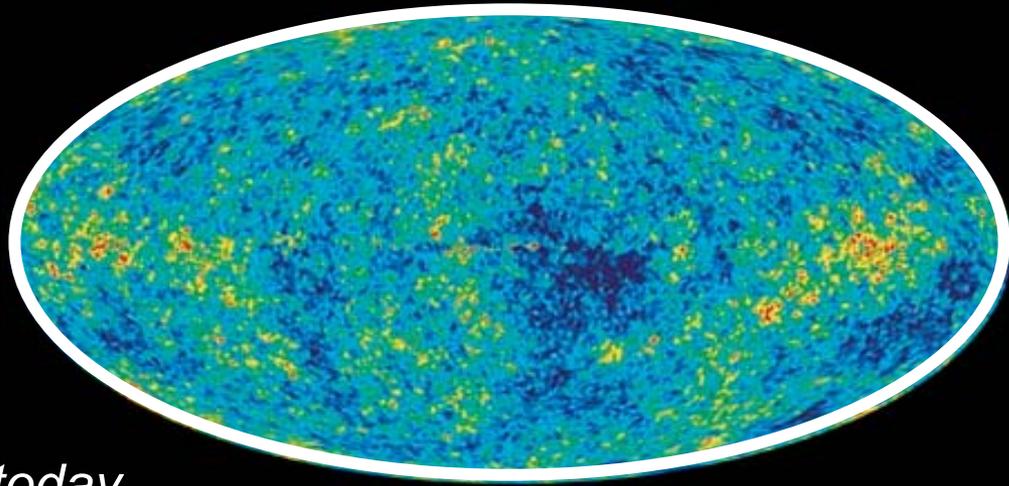
MAP990569

WMAP

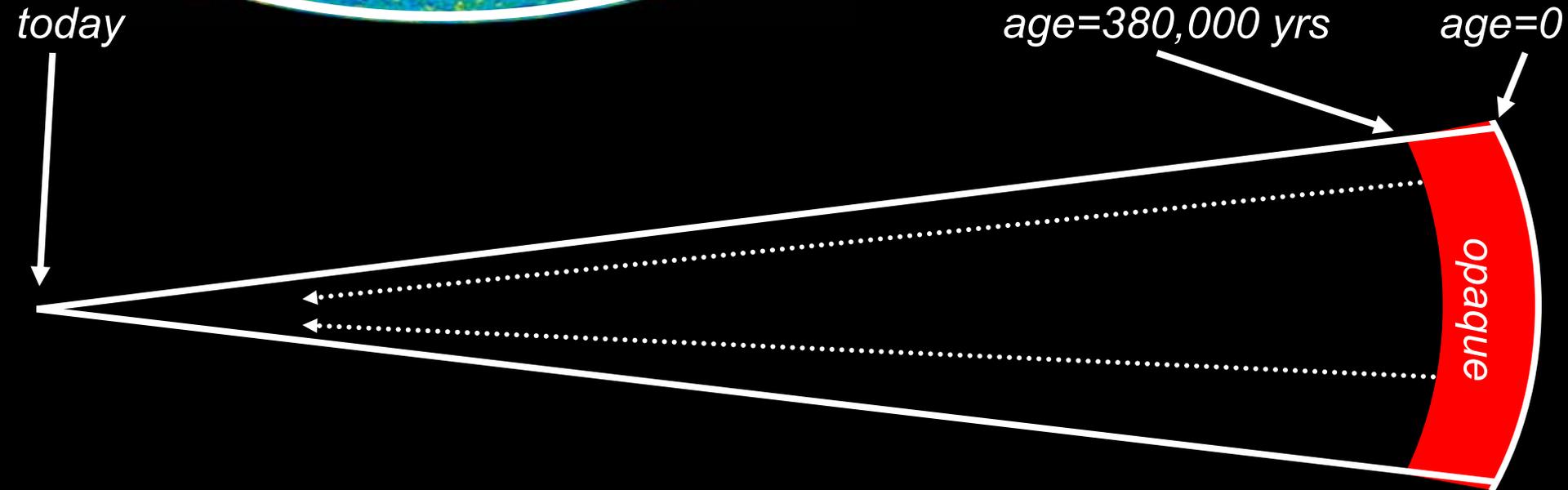
2.99997° 3° 3.00003°



Looking out in space is looking back in time.



**CBR: a snapshot of the
universe 380,000 AB**



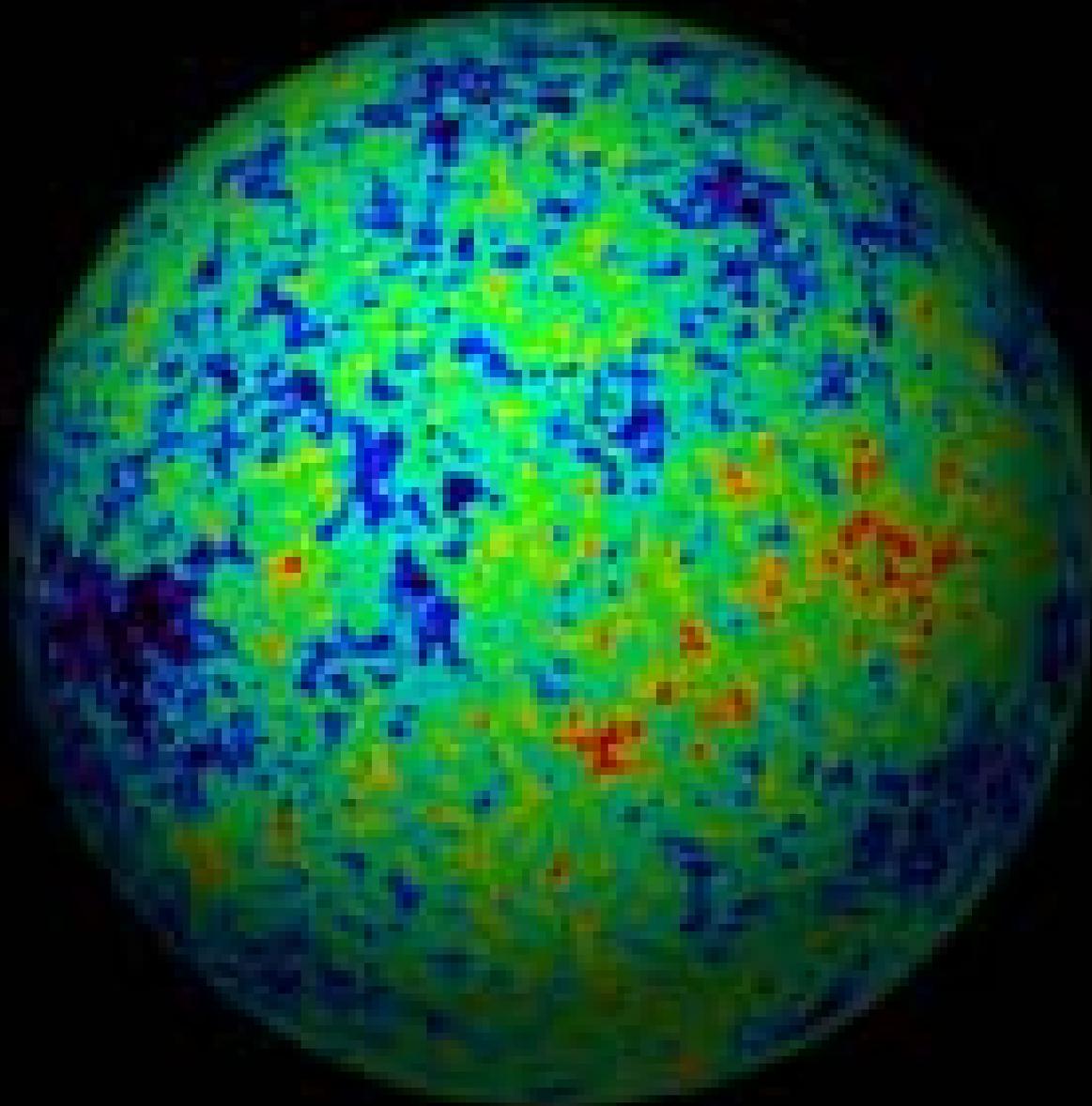
Sloan Digital Sky Survey: Map of the Universe



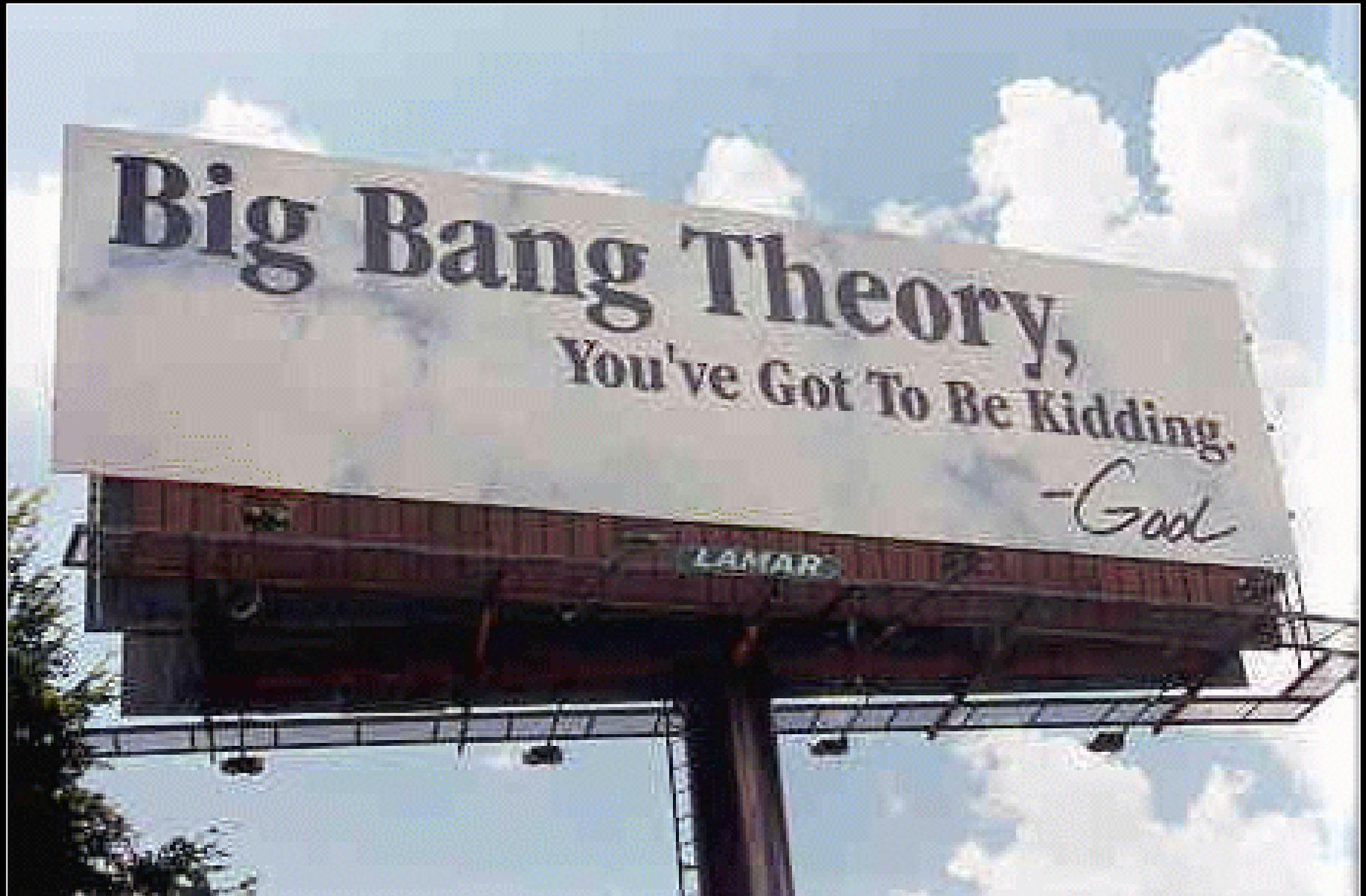
The Last Scattering Surface



The Last Scattering Surface



The Big Bang



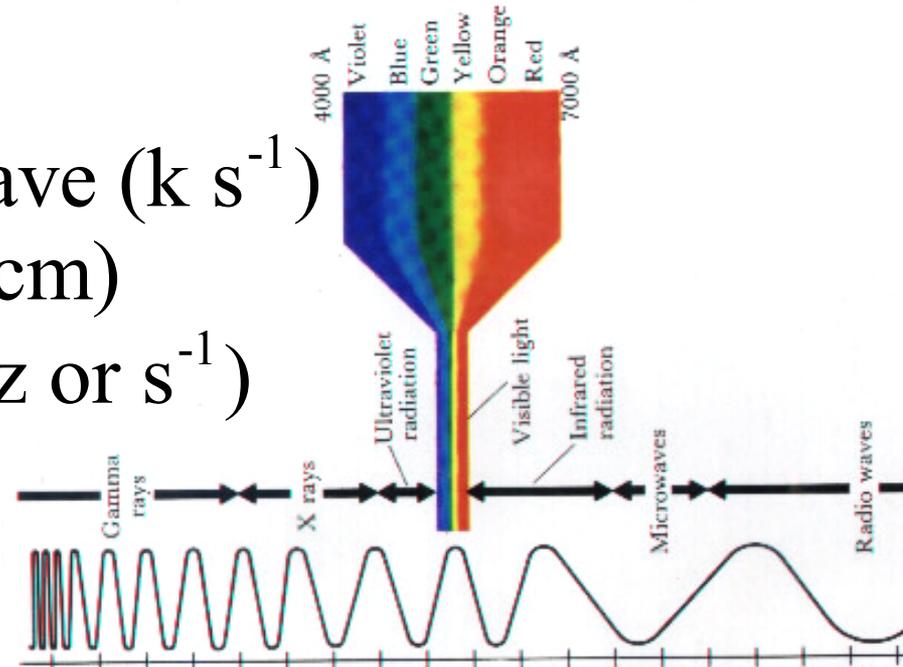
Cosmological Weather Report

- **Today $T=3K$**
- **Yesterday was hotter!**
- **Tomorrow will be colder!**

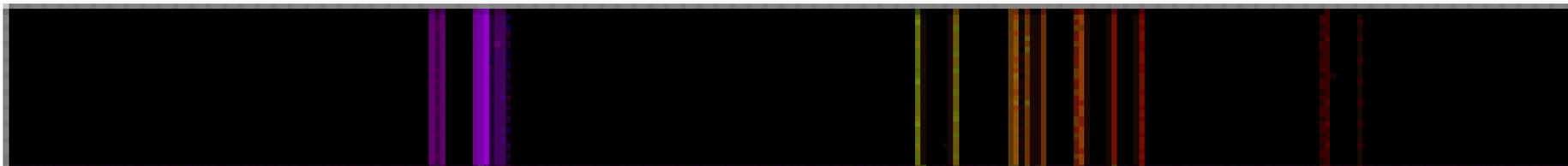
Facts about light

1. Light is a wave

$$c = \lambda \nu \quad \left\{ \begin{array}{l} c = \text{velocity of wave (k s}^{-1}\text{)} \\ \lambda = \text{wavelength (cm)} \\ \nu = \text{frequency (Hz or s}^{-1}\text{)} \end{array} \right.$$

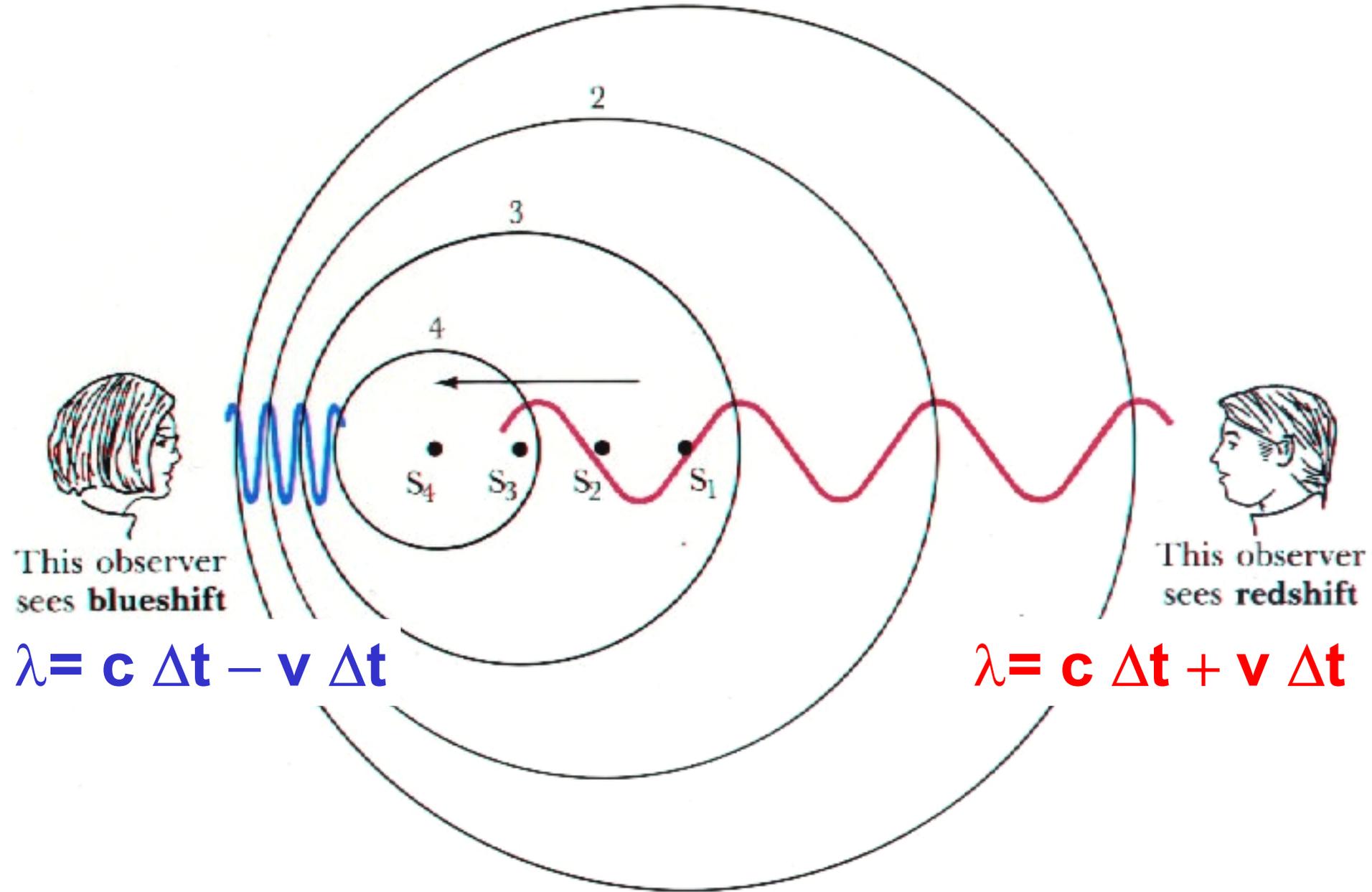


2. The wavelength is quantized



Visible Emission Spectrum

3. Doppler shift



4. Light is a particle

- **Particles of light are “photons”**
- **Photons have energy**

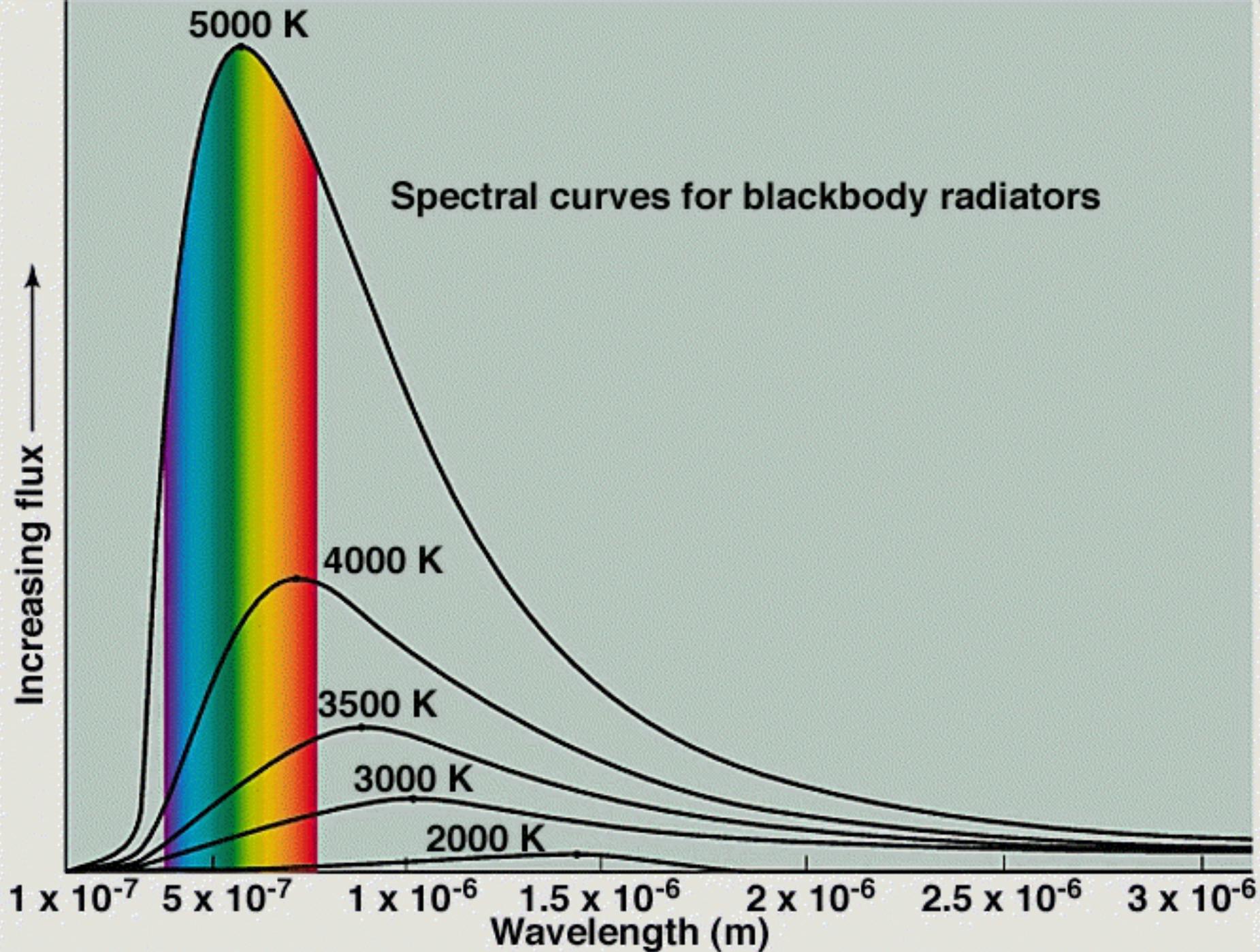
$$E_{\gamma} = h\nu = hc/\lambda \quad h = \text{Planck's constant}$$

(unit of the quantum)

- **Temperature is a measure of energy of the photons**

$$\langle E_{\gamma} \rangle = h \langle \nu \rangle = k_B T \quad k_B = \text{Boltzmann's constant}$$

$$\langle \dots \rangle = \text{average}$$



4. Light is a particle

- **Particles of light are “photons”**
- **Photons have energy**

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- **If wavelength stretched, E decreases, T decreases**

Energy of photons decrease

- **Where does the energy go?**
- **What about conservation of energy?**

Conservation of Energy?

Classical physics: $\frac{dE}{dt} = 0 \Rightarrow E = \text{constant}$

energy, momentum, mass

Special relativity:
($E = mc^2$ and all that)

$$\frac{dT^{\mu\nu}}{dx^\mu} = 0$$

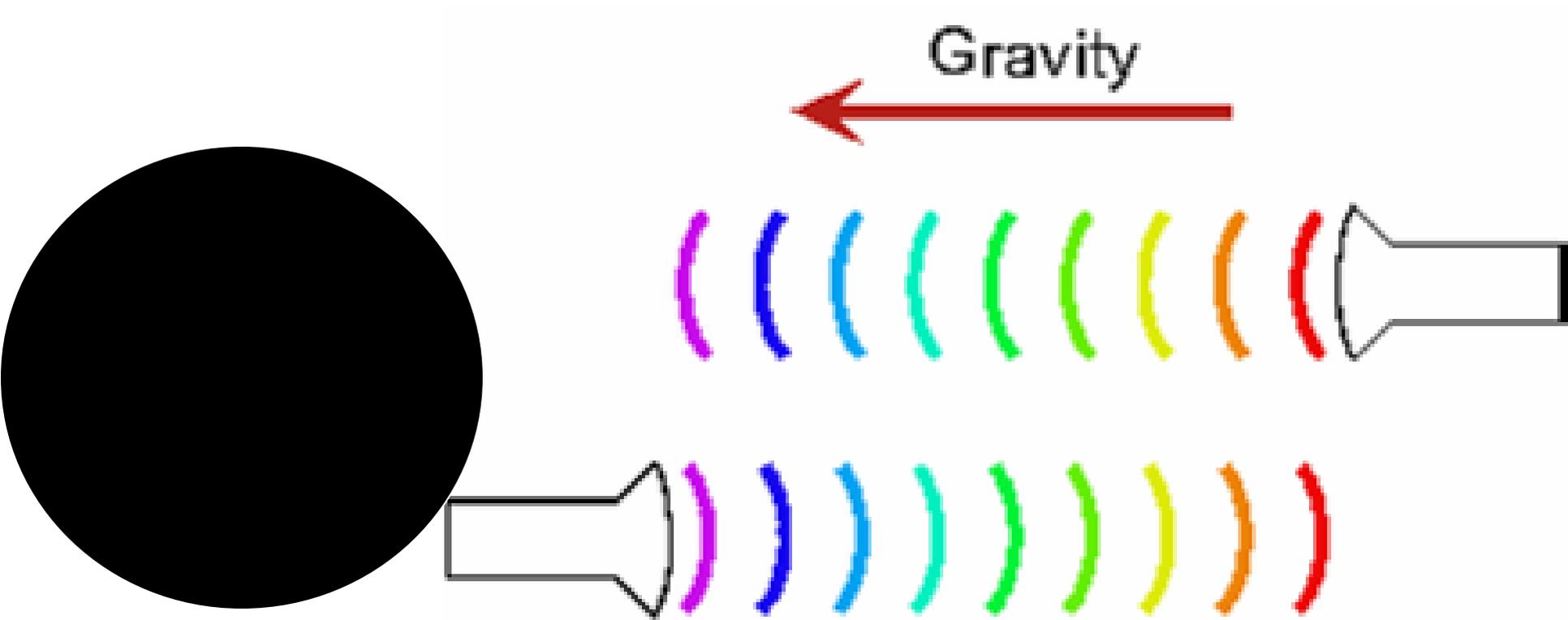
space and time

General relativity:
(gravity)

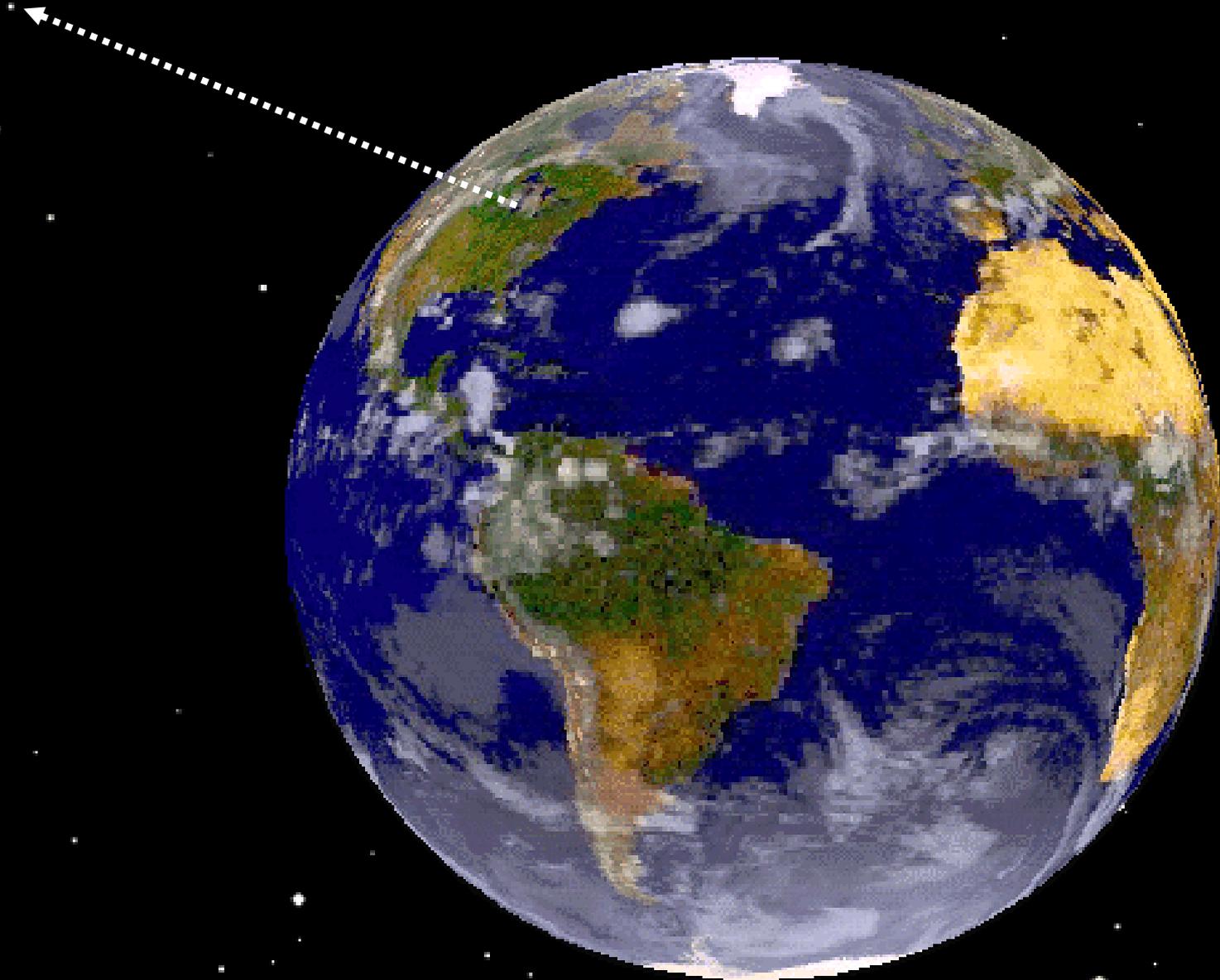
$$\frac{dT^{\mu\nu}}{dx^\mu} + \Gamma_{\mu\alpha}^{\mu} T^{\alpha\nu} + \Gamma_{\mu\alpha}^{\nu} T^{\mu\alpha} = 0$$

gravity

Gravitational redshift



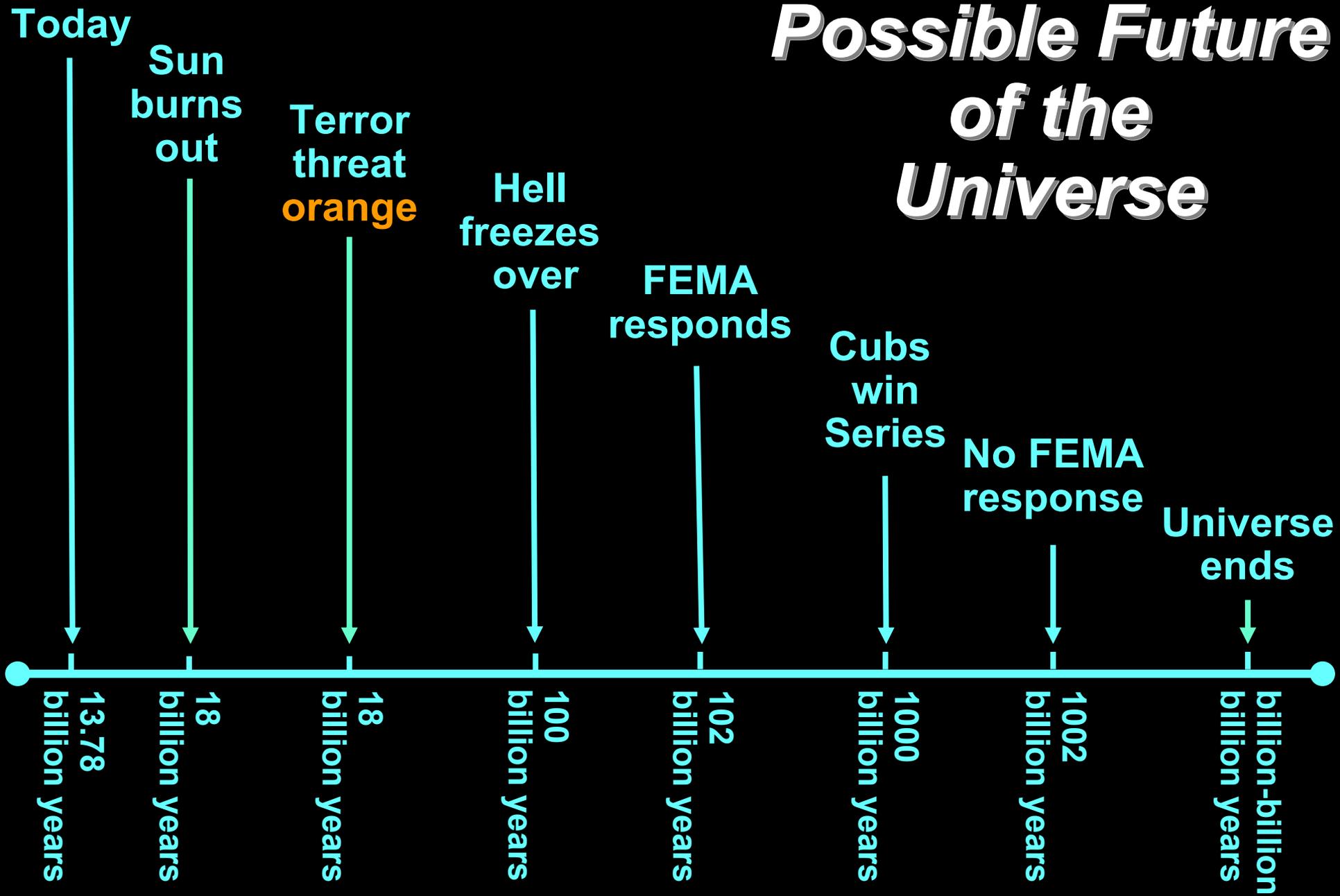
Gravitational redshift



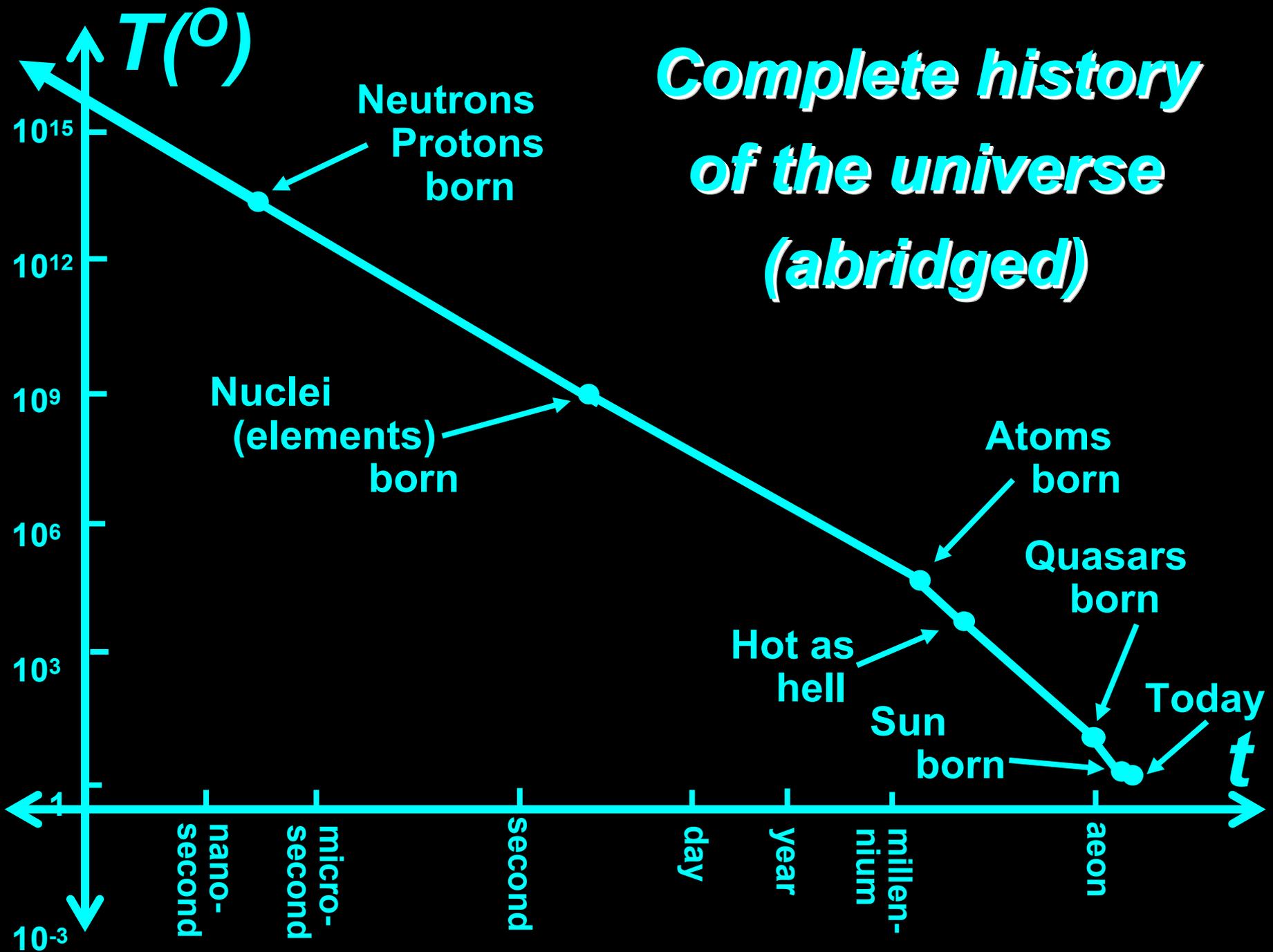
Cosmological Weather Report

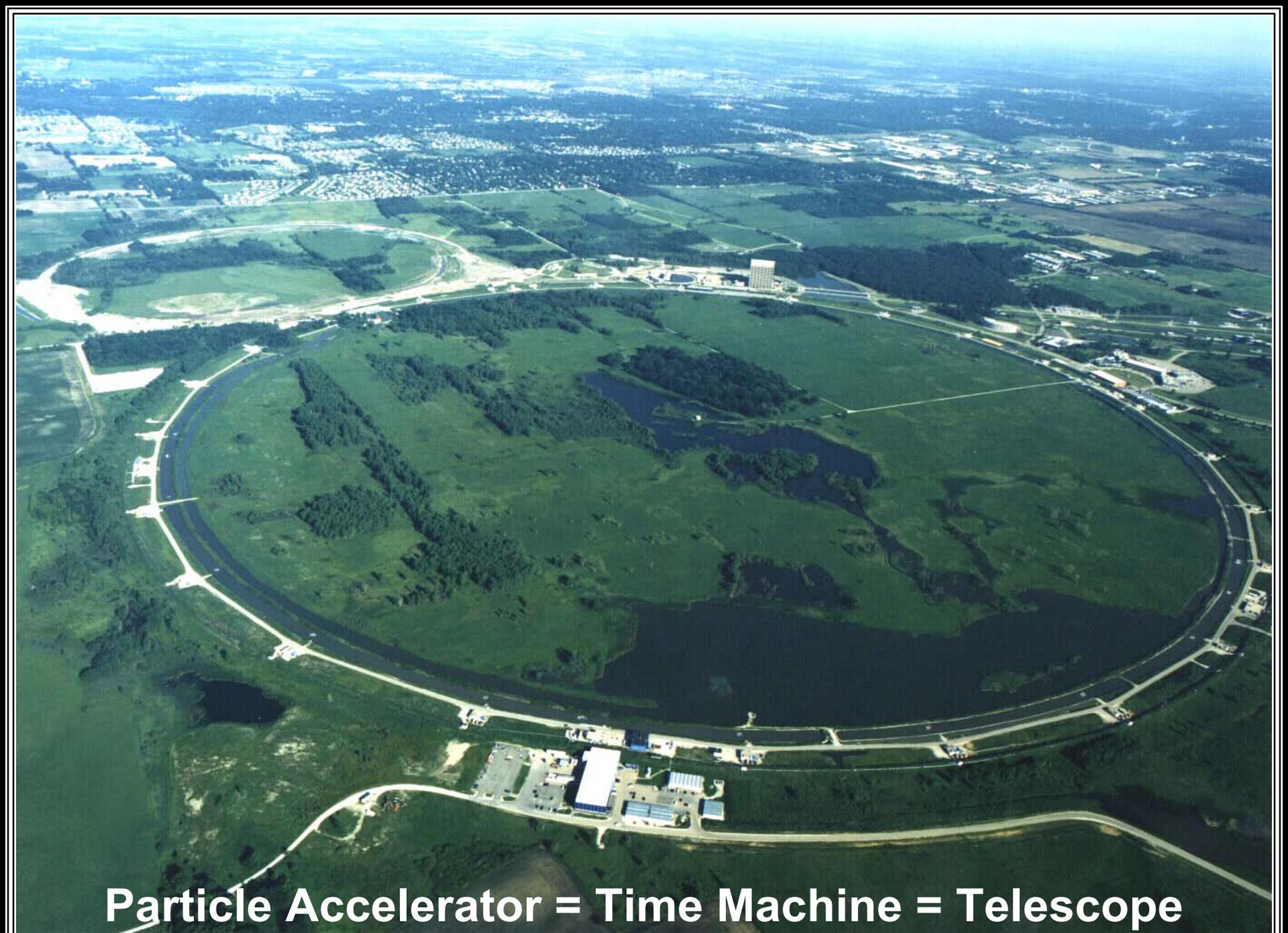
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Possible Future of the Universe



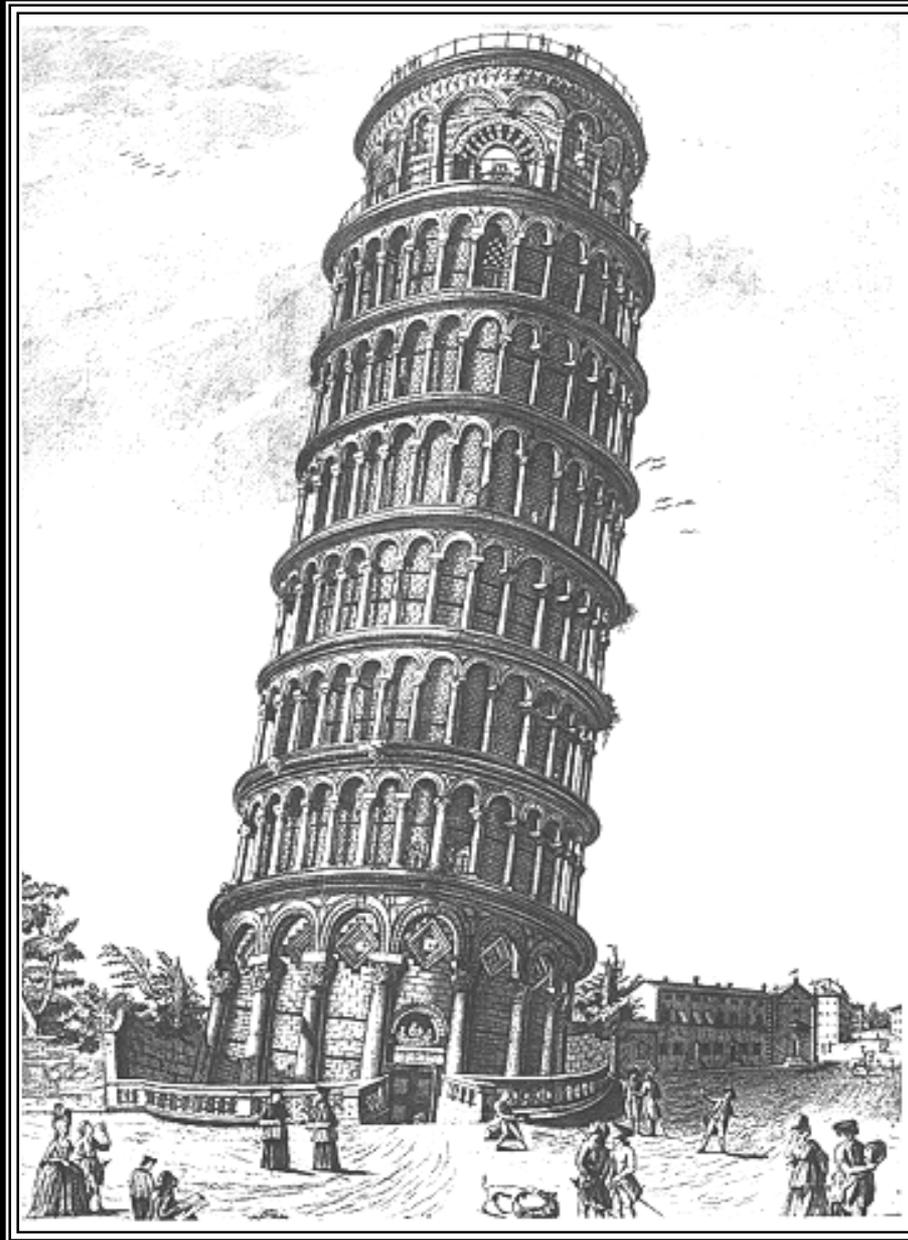
Complete history of the universe (abridged)





Particle Accelerator = Time Machine = Telescope

Galileo's Accelerator





Fermilab's



Primordial

SOUP

EVERYTHING IN THE UNIVERSE



MICROWAVE RADIATION

SUPERCLUSTERS OF GALAXIES

CLUSTERS OF GALAXIES

STARS

PLANETS

PEOPLE

POODLES

PIGEONS

PETUNIAS

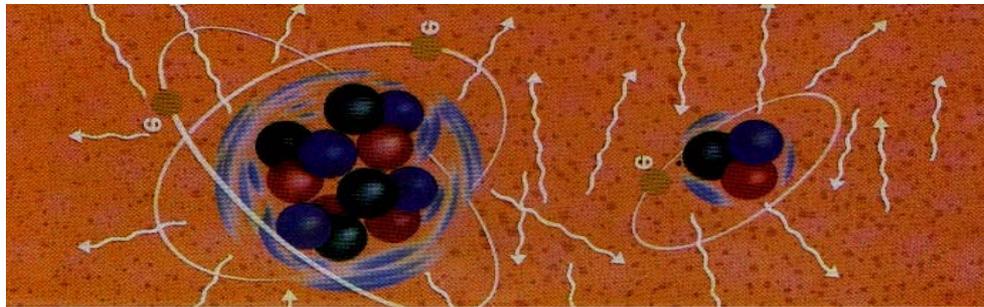
POND SCUM

KARL ROVE



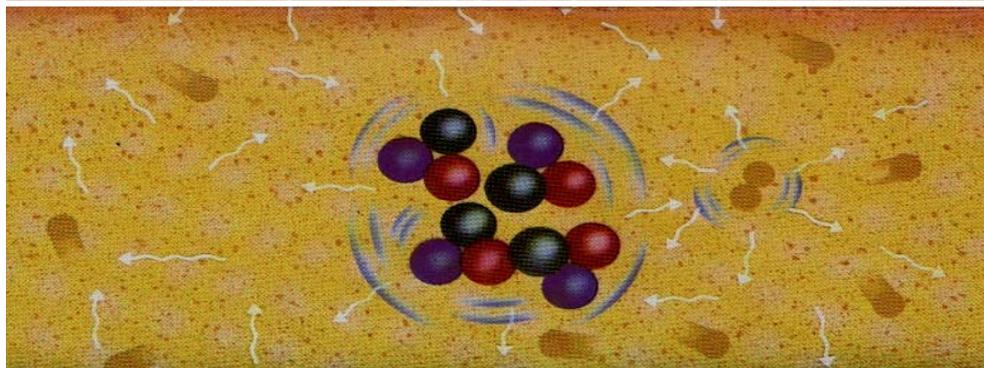
FROM THE PRIMORDIAL SOUP!

**380,000
years**



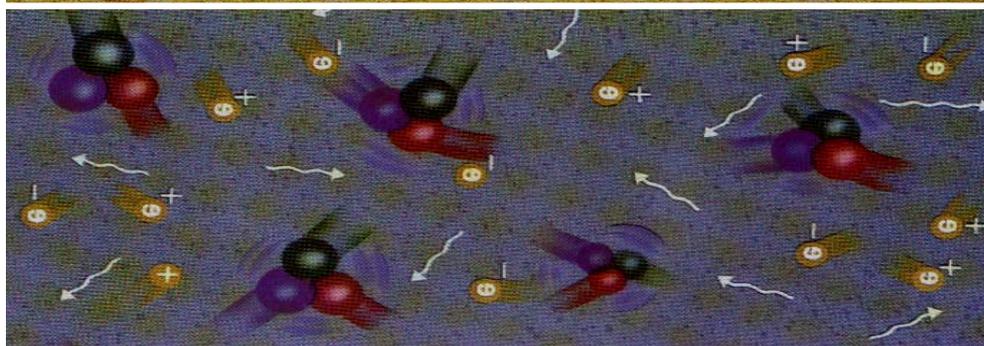
**atoms
form**

**3
minutes**



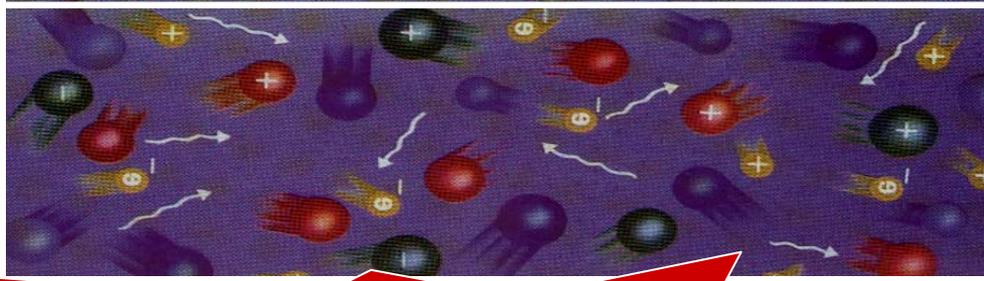
**nuclei
form**

**1-micro
second**



**neutrons
protons
form**

**4-pico
seconds**



**primordial
soup**

BANG!

Periodic table - chemist

H																		He
Li	Be											B	C	N	O	F		Ne
Na	Mg											Al	Si	P	S	Cl		Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br		Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I		Xe
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At		Rn
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub							
			La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb		Lu
			Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No		Lr

Periodic table - cosmologist

H

He

Metals

The Universe today:

73% Hydrogen (10^{-5} ^2H -deuterium)
26% Helium (10^{-5} ^3He)
1% Metals

The Universe 3 minutes AB:

76% Hydrogen (10^{-5} ^2H -deuterium)
24% Helium (10^{-5} ^3He)
 $10^{-8}\%$ Lithium